



15th Tihany Symposium on Radiation Chemistry



Program and Abstracts

23 August – 28 August, 2024
Eger, Hungary

SPONSORS

HUN-REN Centre for Energy Research (HUN-REN CER)



International Atomic Energy Agency (IAEA)



Institute of Isotopes Co. Ltd



Radchem – Solution for Isotope Applications



crmSPACE GmbH, Frankfurt, Germany



ORGANIZED BY

**Hungarian Research Network Centre for Energy Research
Radiation Chemistry Group, Surface Chemistry and Catalysis Department,
Institute for Energy Security and Environmental Safety in co-operation
with the International Atomic Energy Agency**

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VENUE

Eger, Hungary
Eger Park & Hotel
3300 Eger, Szálloda út 1-3.

PROGRAM

AUG 23, Friday

19:00 **Opening, greetings. Dinner**

AUG 24, Saturday

Session 1: FUNDAMENTAL PROCESSES IN RADIATION CHEMISTRY

Chair: Nicholas Green

Invited lectures

10:00 – 10:30 Tamon Kusumoto
O1 WHAT IS THE MECHANISM OF FLASH EFFECTS:
DISCUSSION FROM RADIATION CHEMISTRY
VIEW

Contributed talks

10:30 – 10:50 Josef Sabol
O2 CHARACTERISTICS OF THE EFFECTS OF
CHEMICAL (C) AND BIOLOGICAL (B) AGENTS
WITH THE RISK RESULTING FROM
RADIOLOGICAL (R) AND NUCLEAR
COMPONENTS OF CBRN

10:50 – 11:10 Josef Sabol
O3 MINIMISING THE EFFECTS OF CBRN
SUBSTANCES AND EVENTS ON BUILDINGS AND
INFRASTRUCTURE

11:10 – 11:30 Libor Juha
O4 BEYOND EUV LITHOGRAPHY: DIRECT
NANOSTRUCTURING INDUCED BY EUV/X-RAY
LASERS

11:50 – 14:00 **LUNCH BREAK**

Session 2: LÁSZLÓ WOJNÁROVITS 80 YEARS I

Chair: Erzsébet Takács

14:00 – 14:30 Mark Driscoll
O5 THE ROAD FROM ENVIRONMENTAL CHEMIST TO
RADIATION CHEMIST, A TRIBUTE LÁSZLÓ
WOJNÁROVITS

14:30 – 15:00 Mohamad Al-Sheikhly
O6 ON THE SUCCESSFUL COLLABORATION
BETWEEN HUNGARY AND UNITED STATES ON
DEVELOPING SOLID AND AQUEOUS BASED
DOSIMETRY SYSTEMS FOR RADIATION
PROCESSING

15:00 – 15:30 Vladimir Feldman
O7 RADIATION CHEMISTRY OF FROZEN
INTERMOLECULAR COMPLEXES: BUILDING NEW
SPECIES UNDER EXTREMELY COLD CONDITIONS

15:30 – 16:00 **COFFEE BREAK**

Session 3: LÁSZLÓ WOJNÁROVITS 80 YEARS II

Chair: Róbert Schiller

16:00 – 16:30 Jay LaVerne
O8 RADIATION CHEMISTRY OF WATER AT
INTERFACES IN ELECTRON MICROSCOPY

16:30 – 17:00 Piotr Ulanski
O9 KINETICS AND MECHANISM OF RADIATION-
INDUCED REACTIONS IN POLYMERS – STUDIES
INSPIRED BY THE WORKS OF LÁSZLÓ
WOJNÁROVITS

17:00 – 17:30 Xavier Coqueret
O10 RECENT DEVELOPMENTS IN QUANTIFYING
RADIATION-INDUCED CHAIN COUPLING AND
SCISSION IN POLYMERS

19:00 – **DINNER**

20:15 – Evening Optional Program from 8:00 PM - Szépasszony
Valley
(Details in the back of the book)

AUG 25, Sunday

Session 4: APPLICATION – POLYMERS

Chair: Xavier Coqueret

Invited lectures

- | | |
|---------------|---|
| 10:00 – 10:30 | Luis Ferreira |
| O11 | RADIATION PROCESSING – NEW APPROACHES FOR ADVANCED POLYMER-BASED MATERIALS |
| 10:30 – 11:00 | László Mészáros |
| O12 | EFFECT OF GAMMA IRRADIATION POST-TREATMENT ON THE MECHANICAL AND THERMAL PROPERTIES OF MATERIAL OF JETTING-PRINTED PHOTOPOLYMER SAMPLES |

Contributed talks

- | | |
|---------------|--|
| 11:00 – 11:20 | Lóránt Kiss |
| O13 | EXPLORING THE MECHANICAL HYSTERESIS PROPERTIES OF VULCANIZATES CONTAINING GROUND TIRE RUBBER, SURFACE ACTIVATED THROUGH WATER RADIOLYSIS-BASED TREATMENT |
| 11:20 – 11:40 | Gabriela Tataru |
| O14 | RADIATION-INDUCED CONSOLIDATION OF THE THERMO-PHYSICAL PROPERTIES OF 3D-PRINTED MATERIALS |
| 11:40 – 12:00 | Ademar Lugao |
| O15 | RADIATION PROCESSING OF POLYMERS: IS IT STILL RELEVANT? NEW CHALLENGES AND OPPORTUNITIES |

12:00 – 14:00 **LUNCH BREAK**

Session 5: ENVIRONMENTAL PROTECTION I

Chair: Slobodan Masic

Invited lectures

- | | |
|---------------|--|
| 14:00 – 14:30 | Mohamad Al-Sheikhly |
| O16 | SYNTHESIS OF NOVEL CO ₂ SORBENTS THROUGH RADIATION-INDUCED GRAFT POLYMERIZATION REACTIONS |
| 14:30 – 15:00 | Libing Chu |
| O17 | DEGRADATION OF A STEROID ANDROSTENEDIONE IN AQUEOUS SOLUTION USING IONIZING IRRADIATION |

Contributed talks

- 15:00 – 15:20 Yongxia Sun
O18 DEGRADATION OF TETRACYCLINE IN AQUEOUS
SOLUTION BY ELECTRON BEAM: KINETICS AND
DEGRADATION MECHANISM
- 15:20 – 15:40 Ece Ergun
O19 GAMMA RADIATION/H₂O₂ TREATMENT OF
SELECTED EMERGING CONTAMINANTS:
EXPERIMENTAL AND THEORETICAL
EVALUATION
- 15:40 – 16:00 **COFFEE BREAK**

Session 6: ENVIRONMENTAL PROTECTION II

Chair: Mohamad Al-Sheikhly

Invited lecture

- 16:00 – 16:30 Jianlong Wang
O20 APPLICATION OF ELECTRON BEAM FOR
WASTEWATER TREATMENT IN CHINA: CURRENT
STATUS AND PROSPECTS

Contributed talks

- 16:30 – 16:50 Shijun He
O21 ELECTRON BEAM TECHNOLOGY FOR THE HIGH
CONCENTRATED UDMH SOLUTION TREATMENT
- 16:50 – 17:10 Shizong Wang
O22 ELECTRON BEAM RADIATION COUPLED WITH
FLOCCULATION PROCESS FOR ADVANCED
TREATMENT OF COKING AND DYEING
WASTEWATER: PERFORMANCE AND
SYNERGISTIC EFFECTS
- 19:00 – **DINNER**
- 20:00 – 22:00 **Bowling evening**
(Details in the back of the book)

AUG 26, Monday

Session 7: ENERGY SAVING

Chair: László Wojnárovits

Invited lecture

- 10:00 – 10:30 Sophie Le Caër
O23 PREDICTING DEGRADATION MECHANISMS IN LITHIUM BISTRIFLIMIDE “WATER-IN-SALT” ELECTROLYTES FOR AQUEOUS BATTERIES
- 10:30 – 11:00 Maria Helena Casimiro
O24 IAEA’S ROLE IN THE DEVELOPMENT AND EMERGING TRENDS ON RADIATION TECHNOLOGY APPLICATIONS

Contributed talks

- 11:00 – 11:20 Islam Mustafayev
O25 LOW-CARBON RADIATION CHEMICAL PROCESSES OF PRODUCTION OF OLEFINS FROM OIL FRACTIONS
- 11:20 – 11:40 Hanqin Weng
O26 TRANSIENT PROCESSES FOR THE RADIOLYSIS OF DIAMIDE PHENANTHROLINE IN 1-OCTANOL
- 11:40 – 12:00 Zoltán Juhász
O27 LABORATORY ASTROCHEMICAL STUDIES ON ION-IRRADIATED ICE ANALOGUES FOR THE JUICE MISSION
- 12:00 – 12:20 Kristýna Havlinová
O28 GGAG:Ce³⁺@SiO₂-RB COMPOSITE FOR RADIODYNAMIC THERAPY
- 12:20 – 14:00 **LUNCH BREAK**

Session 8: BIOPOLYMERS

Chair: Jay LaVerne

Invited lectures

- 14:00 – 14:30 Monique Lacroix
O29 THE ROLE OF IRRADIATION IN THE DEVELOPMENT OF ECO-FRIENDLY ACTIVE FOOD PACKAGING
- 14:30 – 15:00 Wanvimol Pasanphan
O30 ELECTRON-BEAM REINVENTING BIO-BASED POLYMERS AND SUSTAINABLE MATERIALS TO FUNCTIONAL MICRO/NANOSTRUCTURES FOR NET-ZERO INDUSTRY

Contributed talks

- 15:00 – 15:20 Philip Marinov
O31 EFFECT OF IONIZING RADIATION ON THE
ACTIVITY OF ENZYMES
- 15:20 – 15:40 Mark Driscoll
O32 OPTIMIZATION OF CELLULOSE AND ALPHA
CELLULOSE SOLUBILITY IN SODIUM HYDROXIDE
- 15:40 – 16:00 **COFFEE BREAK**

Session 9: BIOPOLYMERS, FOOD IRRADIATION

Chair: Mark Driscoll

Invited lecture

- 16:00 – 16:30 Joseph Robertson
O33 SINGLE MOLECULE APPROACHES TO STUDYING
RADIATION-INDUCED LESIONS IN DNA

Contributed talks

- 16:30 – 16:50 Joana Madureira
O34 GAMMA RADIATION: A TECHNOLOGY TO
ENHANCE THE EXTRACTABILITY OF BIOACTIVE
COMPOUNDS FROM OLIVE WASTES FOR FOOD
APPLICATIONS
- 16:50 – 17:10 Aleksandar Krleski
O35 DEVELOPMENT OF AN EFFICIENT PROTOCOL FOR
THE EFFECTIVE USE OF LABORATORY
RESOURCES FOR THE IMPLEMENTATION OF
COUNTRYWIDE CONTROL AND MONITORING OF
IRRADIATED FOOD

Session 10: POSTER SESSION

17:10 – 19:00

19:00 **DINNER**

AUG 27, Tuesday

Session 11: NANOMATERIALS

Chair: Piotr Ulanski

Invited lectures

- | | |
|--------------|---|
| 9:00 – 9:30 | Tanja Jurkin |
| O36 | GAMMA IRRADIATION AS AN EFFICIENT
TECHNIQUE FOR THE SYNTHESIS OF MAGNETIC
NANOSTRUCTURES |
| 9:30 – 10:00 | Masao Gohdo |
| O37 | INVESTIGATION OF RHODAMINE NANO-CLAY
RADIO-FLUOROGENIC GEL DOSIMETERS BY
PHOTOLUMINESCENCE-DETECTED PULSE
RADIOLYSIS |

Contributed talks

- | | |
|---------------|--|
| 10:00 – 10:20 | Lenka Prouzová Procházková |
| O38 | RADIATION STABILITY OF NANOCOMPOSITE
SCINTILLATORS |
| 10:20 – 10:40 | Gergő Lakatos |
| O39 | ASTROCHEMISTRY OF CALCIUM CARBONATE –
THE ROLE OF LOW-ENERGY PROTON
IMPLANTATION |
| 10:40 – 11:00 | Beata Rurarz |
| O40 | RADIATION-SYNTHESIZED POLY(ACRYLIC ACID)
NANOGELES AS RADIOISOTOPE CARRIERS FOR
CANCER THERANOSTICS. FROM SYNTHESIS TO
ANIMAL STUDIES |
| 11:00 – 11:20 | Semiha Duygu Sütekin |
| O41 | MODULATING HYDROLYSIS AND ZETA
POTENTIAL IN AMINE-FUNCTIONALIZED
NANOGELES: SYNTHESIS, SIZE CONTROL AND PH
RESPONSIVE PROPERTIES |
| 11:40 – 14:00 | LUNCH BREAK |
| 14:00 – 18:00 | CONFERENCE EXCURSION |
| 19:30 – 22:30 | CONFERENCE DINNER |

**Closing remarks and award ceremony of Best Poster and
Best Oral Presentation**

AUG 28, Wednesday TRAVEL HOME

POSTER SESSION

AUG 26, Monday

17:10 – 19:00

- P1** A. Horynová, V. Hájková, Š. Jelínek, J. Chalupský, V. Vozda, L. Vyšín, J. Bulíčka, T. Burian, R. Dudžák, M. Krupka, Z. Kuglerová, J. Krása, N. Medvedev, L. Fekete, L. Juha for PBS/CDL Damage Collaborations
RADIOLYSIS OF LEAD IODIDE AND RELATED PEROVSKITE MATERIALS INDUCED BY XUV/X-RAY LASERS AND OTHER SOURCES
- P2** O. Riabukhin, T. Maksimova, D. Maksimkin
OPTICAL PROPERTIES EVALUATION OF STERILIZED PET BLOOD TEST TUBES
- P3** T. Kusumoto, Y. Okazaki, M. Fromm, S. Roux, R. Bazzi, R. Hirayama, S. Kodaira, J. Kataoka
INCREASE OF YIELDS OF HYDROXYL RADICALS DUE TO THE DECOMPOSITION OF HYDROGEN PEROXIDE BY GOLD NANOPARTICLES UNDER PROTONS AND HEAVY IONS
- P4** M. D'Angelantonio, G. Petrone, A. Kovtun, M. Melucci, V. Palermo, A. Liscio
GAMMA-RAY ASSISTED REDUCTION OF GRAPHENE OXIDE THIN FILMS: PRELIMINARY RESULTS
- P5** S. Kadlubowski, T. Balogh, P. Ulanski
INFLUENCE OF IONIZING RADIATION ON POLY(N-VINYL-2-PYRROLIDONE) IRRADIATED IN SOLID STATE AND AQUEOUS SOLUTIONS
- P6** E. Ergun, Hilal B.D. Halkman, A. Fitoz, Ö. Kantoğlu, Ü. Ergun, E. Orhan
UTILIZING GAMMA IRRADIATION WITH GREEN ANTIBACTERIAL AGENTS AS A PROMISING ALTERNATIVE FOR PRESERVING HISTORICAL TEXTILES
- P7** E. Suljovrujic, D. Milicevic, D. Milivojevic, H. Lewandowska, J. Sadlo, E. Džunuzović, G. Stamboliev
THE INFLUENCE OF DIFFERENT RADIATION MODALITIES ON POST-IRRADIATION BEHAVIOUR AND PROPERTIES OF HIGHLY CRYSTALLINE PP
- P8** E. Furu, R. Huszánk
PROTON BEAM DEGRADATION OF IBUPROFEN IN-AIR
- P9** Z. Khalilov
GAMMA FACILITY, IRRADIATION APPLICATIONS IN AZERBAIJAN

- P10** F.L. Zorila, M. Ene, D.C. Negut, L. Trandafir, A.S. Dumbrava, M. Constantin, A.S. Baltac, C. Acomanoai, M. Alexandru
CELL VIABILITY AND METABOLIC CHANGES IN *STAPHYLOCOCCUS AUREUS* FOLLOWING GAMMA IRRADIATION UNDER DIFFERENT CONDITIONS
- P11** R. Homlok, M. Elsherbeny, Cs. Mohácsi-Farkas, Á. Belák
CHANGES IN ANTIBIOTIC SUSCEPTIBILITY OF *STAPHYLOCOCCUS AUREUS* STRAINS DUE TO GAMMA IRRADIATION AND DIFFERENT SALT CONCENTRATIONS
- P12** R. Homlok, T. Kocsis
IONIZING RADIATION EFFECTS ON OPPORTUNISTIC PATHOGENIC BACTERIAL STRAINS IN THE PRESENCE OF PIPERACILLIN
- P13** M. Kovács, A. Tegze, R. Homlok, L. Wojnárovits, Cs. Mohácsi-Farkas, E. Takács, Á. Belák
APPLICATION OF GAMMA RADIATION IN ORDER TO PREVENT THE SPREAD OF ANTIBIOTIC RESISTANCE IN *STAPHYLOCOCCUS AUREUS*
- P14** S.D. Sütekin, N.A. Aimanova, A.A. Mashentseva, M. Barsbay
GAMMA RADIATION-INDUCED SYNTHESIS OF PVP-STABILIZED PALLADIUM NANOPARTICLES ON CELLULOSE FOR PHOTOCATALYTIC DEGRADATION OF CIPROFLOXACIN
- P15** Y. Kumagai, A. Koshizaka, R. Ikarugi, T. Oka, J. Kumagai, Y. Kitatsuji
HYDROGEN PRODUCTION FROM RADIOLYSIS OF WATER-CONTAINING URANIUM OXIDE POWDERS
- P16** D. Milicevic, D. Milivojevic, S. Galovic, K. Djordjevic, E. Džunuzović, D. Dudić, E. Suljovrujić
THE INFLUENCE OF ORIENTATION ON THE FREE-RADICAL EVOLUTION IN DIFFERENT POLYETHYLENES EXPOSED TO GAMMA RADIATION
- P17** A. Baltac, I. Atkinson, D. Culita, R. Mitran, D. Neguț, M. Alexandru, F. Zorilă
ANTIMICROBIAL DELIVERY SYSTEMS CONTAINING MESOPOROUS SILICA AND SILVER NANOPARTICLES OBTAINED THROUGH GAMMA IRRADIATION
- P18** R. Wach, M. Olejniczak, B. Rokita, A. Olejnik
DENATURATION OF FISH COLLAGEN EXPOSED TO IONIZING RADIATION USED STERILIZATION

- P19** G. Albarrán, K.E. Collins, C.H. Collins
RADIOLYTIC PRODUCT DISTRIBUTION IN SELF-IRRADIATED AND GAMMA IRRADIATED SOLID STATE $\text{Ca}^{14}\text{CO}_3$: NEW DATA
- P20** A. Bezsenyi, E. Takács
THE FUTURE OF γ -RADIATION MODELED AOP (ADVANCED OXIDATION PROCESSES) IN WASTEWATER TREATMENT
- P21** K. Kovács, A. Tegze, A. Bezsenyi, L. Wojnárovits
A SPECTRAL AND KINETIC STUDY ON DEGRADATION OF METOPROLOL USING HIGH ENERGY IONIZING RADIATION
- P22** A. Zaouak, H. Chouchane, H. Jelassi
PERFORMANCE AND DEGRADATION PATHWAYS OF QUIZALOFOP ETHYL AN EMERGING POLLUTANT BY IONIZING RADIATION IN AQUEOUS SOLUTION
- P23** M. Virgolici, F. Albota, E. Ionuz, A. Ficai, S. Vasilca, A. Serban, M. Cutrubinis, D. Constantinescu, V. Moise
MODIFIED ATMOSPHERE AND TEMPERATURE GAMMA IRRADIATION EXPLORATORY STUDIES ON EVALUATING POLYOLEPHINES RECYCLING POTENTIAL
- P24** Aijuan Zhou, Rui Han, Yong Liu
SELECTIVE OXIDATION OF AMMONIA NITROGEN TO DINITROGEN BY A TETRAVALENT IRON OXIDE COMBINED WITH A SULFITE REDUCTION PROCESS UNDER UV IRRADIATION
- P25** Jun Kumagai, Keisuke Hosomi, Miho Ogiso, Katsuyoshi Horinouchi, Shinya Hasegawa, Kumi Negishi, Masaya Ida, and George Hasegawa
 H_2 EVOLUTION FROM HYDRATED WATER IN CEMENT COMPONENT CRYSTALS VIA γ -RAY RADIOLYSIS: EFFECT OF IRRADIATION TEMPERATURE
- P26** S. Masic, I. Vujcic
DEVELOPMENT OF BIOPOLYMER ACTIVE PACKAGING MATERIALS BASED ON CELLULOSE AND POLYETHYLENE GLYCOL
- P27** L. Kudrevicius, P. H. Castillo, D. Adliene
THE BEHAVIOUR OF METAL PARTICLES ENRICHED POLYMER FILMS IN RADIATION HARSH ENVIRONMENT

- P28** A. Jreije, J. Laurikaitienė, N. Keršienė, P. Griškevičius, D. Adliene
FULLY RECYCLABLE 3D PRINTING COMPOSITES FOR
CUSTOMIZED HEAD IMMOBILIZATION MASKS IN
RADIOTHERAPY
- P29** R. Huszánk, E. Furu,
2 MeV ION IRRADIATION OF PORPHYRIN IN ITS THREE
FORMS
- P30** C. Duss, E. Marchioni, L.J. Charbonnière, J. M. Jung, Florent Kuntz
DOSIMETRY APPLIED TO LOW ENERGY ELECTRON BEAM

Saturday Evening Optional Program from 8:00 PM

Self-financed program

We will visit Szépasszony Valley for a wine-tasting experience.

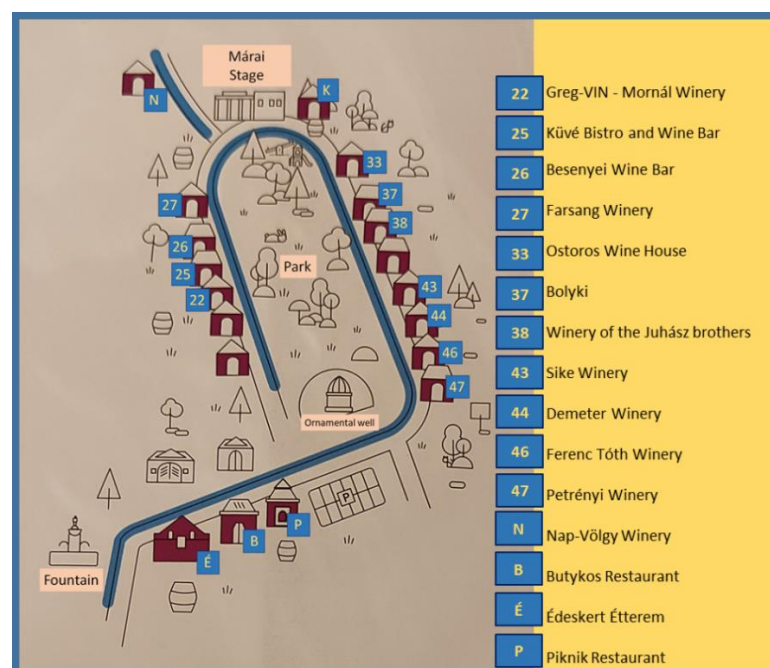
Szépasszony Valley is the largest continuous wine cellar area in Eger, with nearly 200 cellars today. The wineries welcome everyone at any time for a glass of wine on their cozy terraces or in their cellars. Some of the most popular wines include Egri Leányka, Bikavér, and Egri Csillag. Alongside the wines, you can often find cheese, pogácsa (savory pastries), and traditional bread with lard, while some places offer jams and syrups to entice guests.

Even if you're not a wine enthusiast, you are still welcome to join us, as the area is beautiful, and many cellars feature live music in a charming atmosphere.



We will depart from the reception from 8:00 PM. There are two routes to choose from:

- Those who prefer a **walk** can join the group led by **Professor Erzsébet Takács and Professor László Wojnárovits**. The walk is approximately 30 minutes (2 km).
- For those who prefer a quicker option, you can take a **taxi**. The taxi ride takes about 6 minutes and costs around 8-10 euros per trip, accommodating up to 3 people comfortably.



Sunday Evening Optional Program: Bowling Night at London Bar & Bowling

Join us for a fun-filled evening at the **London Bar & Bowling**, located within the hotel (you can enter from the outside), from **8:00 PM to 10:00 PM**. Both bowling lanes are reserved exclusively for conference participants, and you can enjoy **bowling for free!** Special bowling shoes are required to play, which will be provided for you on-site, free of charge.

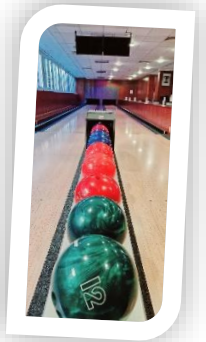


If you prefer billiards, there's also a billiard table available:

2000 HUF (around 5 euros) for 30 minutes

3000 HUF (around 7.5 euros) for 60 minutes

Even if bowling or billiards isn't your thing, don't just stay in your room! Come down and enjoy the great company and the lively atmosphere. The bar offers delicious cocktails, and the fun is guaranteed.

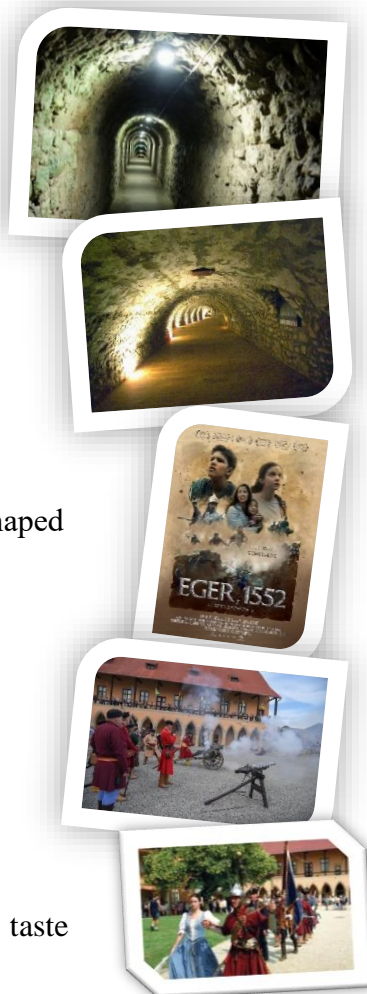


CONFERENCE EXCURSION: Explore the Historic Eger Castle

We will depart from the reception at 2:00 PM.

Prepare for an unforgettable journey through time as we visit the legendary Eger Castle, a symbol of Hungary's rich history and resilience. Our excursion includes a series of exclusive experiences:

- **Guided Tour of the Underground Corridor System**
Discover the hidden depths of the fortress with a guided tour through the mysterious underground corridors (Mine monitoring corridor). This special, enclosed historical site offers a unique glimpse into the past, where temperatures range between 9-20°C. Even in the summer heat, a light sweater and sturdy shoes are recommended for comfort as you navigate these narrow passageways.
- **EGER, 1552 - A Cinematic Journey**
Step into the Egri vár cinema for a captivating short film that retells the dramatic siege of Eger Castle from the perspective of today's youth. Experience the heroism and bravery that shaped Hungary's history through modern eyes.
- **Weapons, Uniforms, and a Parade Shot**
Witness the grandeur of historical military life with a special display of period weapons and uniforms, culminating in a thrilling parade shot demonstration that will transport you back to the days of the castle's defenders.
- **Wine Tasting at Cipóosztó House**
End the day on a high note with a delightful wine tasting session at the charming Cipóosztó House, where you can taste some of the finest local wines in a truly authentic setting.



ORAL PRESENTATIONS

WHAT IS THE MECHANISM OF FLASH EFFECTS: DISCUSSION FROM RADIATION CHEMISTRY VIEW

T. Kusumoto¹, T. Mamiya¹, A. Danvin², Aurelia Arnone², Severine Chefson², Catherine Galindo², Philippe Peaupardin², Quentin Raffy², Nagaaki Kamiguchi³, Daizo Amano³, Kenzo Sasai³, Teruaki Konishi¹, Satoshi Kodaira¹

¹ National Institutes for Quantum Science and Technology (QST), Japan

² Institute Pluridisciplinaire Hubert Curien (IPHC), France

³ Sumitomo Heavy Industries, Ltd. (SHI), Japan

Radiotherapy for cancers performed at ultra-high dose rate (UHDR: > 40 Gy/s) has been attracted due to sparing effects on healthy tissues. To unveil the mechanism of this sparing effect, we have addressed to evaluate yields of water radiolysis products (e.g., hydroxyl radicals, hydrated electrons and hydrogen peroxide) and DNA strand breaks and base damages under protons with 27.5, 55 and 230 MeV. Yields of 7OH-C3CA, which is a fluorescent product produced by reactions between hydroxyl radicals and their scavenger C3CA, decrease with increasing dose rate (Figure 1) [1]. The relative yield change is $-36 \pm 3\%$ between 0.1 and 50 Gy/s under 230 MeV protons. This value agrees with ones under protons with other energies. Similarly, yields of hydrated electrons slightly decrease with dose rate. In comparison, yields of hydrogen peroxide increase very slightly with dose rate, when we add sodium nitrate, which act as a scavenger of hydrated electrons that decompose hydrogen peroxide. This finding implies that radical-radical reactions occur efficiently with dose rate, resulting in the reduction of hydroxyl radicals. Also, yields of SSB and base damage reduce with increasing dose rate. This result also supports complex track structure formed in high-dose region. In the presentation, we will discuss in detail.

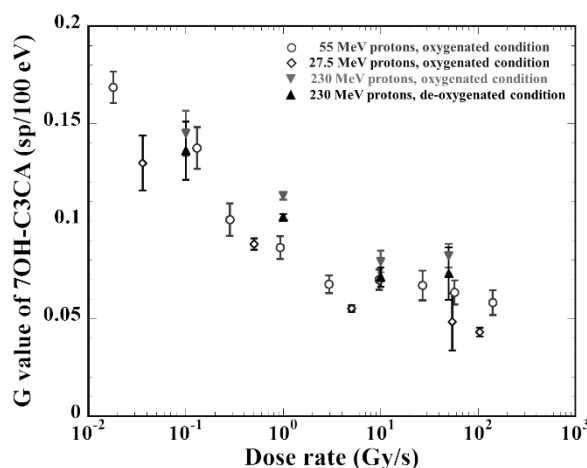


Figure 1. Dose rate dependence of 7OH-C3CA under protons.

References

[1] T. Kusumoto et al., *Radiat. Res.* **2024**, accepted.

CHARACTERISTICS OF THE EFFECTS OF CHEMICAL (C) AND BIOLOGICAL (B) AGENTS WITH THE RISK RESULTING FROM RADIOLOGICAL (R) AND NUCLEAR COMPONENTS OF CBRN

J. Sabol

Police Academy of the Czech Republic in Prague, Department of Crisis Management, Prague, Czech Republic

The paper analyses individual CBRN constituents by assessing their health effects and risk quantification. Special attention is paid to an attempt to express the total dangerous consequences of different contributions from each CBRN component. It has been recognized that there are only limited means how to evaluate the level of danger related to chemical and biological agents. Whereas, it is relatively easy to evaluate the exposure or dose caused by radiological and nuclear materials, since there have been defined and introduced appropriate and adequate quantities and units to express the biological effects of ionizing radiation and radioactive substances. The impact of components R and N on persons is principally realized by ionizing radiation, where stochastic (late) effects at very low levels and deterministic effects (tissue reactions) at high levels are strictly distinguished. One can presume that a similar approach should also be adopted when considering risk due to the effects of chemical (C) and biological (B) agents, where, so far, such an approach has not been strictly introduced. In general, it is similar to this situation, suggesting that we can also expect that the health effects of C and B agents would result in stochastic and deterministic effects. These effects correspond to the amount of dangerous materials inhaled, ingested or in contact with the skin. Biological assumptions and limitations for C and B materials are usually expressed in terms of the median infective dose (ID₅₀) equal to the median lethal dose (LD₅₀) [1]. Low-level exposure is here usually presented as it is related to "No observable effects in the majority of the population". However, this can apply only at higher levels of exposure, while at lower levels, there is no quantity similar to quantities reflecting the stochastic effects of ionizing radiation [2]. More information regarding assessing health effects due to R and N components compared to quantifying harm resulting from C and B exposure is discussed in some detail.

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MINIMISING THE EFFECTS OF CBRN SUBSTANCES AND EVENTS ON BUILDINGS AND INFRASTRUCTURE

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The hazards from different forms of CBRN incidents and their potential to cause contamination are outlined. Risks and vulnerabilities of buildings and infrastructure and mechanisms of penetration are described. Other issues addressed include emergency management and training, limitation of business interruption and relationships between tenants, owners, insurers and other agencies. Guidance is provided on methods for preventing and limiting the spread of contamination in terms of physical and operational security. Guidance on pre-planning for decontamination includes building surveys to identify locations, surfaces, systems, and contents most vulnerable to contamination and strategies that can be adopted to reduce contamination, reduce vulnerability, and facilitate decontamination related to chemical, biological and radioactive materials. Special attention is paid to radiological and nuclear events aimed at the dispersion of radioactive materials following accidents or terrorist attacks involving high-activity radioactive sources (taking into account their chemical and physical properties), nuclear reactors, spent nuclear fuel facilities and nuclear weapons detonations [1,2].

In addition, the paper summarises the main aspects and specifics of protecting the population against CBRN substances released in heavily populated areas, considering the properties of individual CBRN components where difficulties in their monitoring and risk assessment should be taken into account [3].

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BEYOND EUV LITHOGRAPHY: DIRECT NANOSTRUCTURING INDUCED BY EUV/X-RAY LASERS

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Nowadays, the mass production of micro- and nano-structures for highly integrated electronic circuits is dominated by extreme ultraviolet lithography (EUVL). This is a multistep processing technology the key step of which is represented by a transfer and demagnification of structural motifs from either reflective or transmission masks by an electromagnetic radiation having a typical wavelength of 13.5 nm delivered most frequently from optimized laser- and discharge-plasma EUV sources. A latent structure is created in a suitable resist to be etched. After etching, further processing steps must be applied to create a desired three-dimensional structure able to act as a small, highly integrated electronic device. However, a total number of processing steps can be reduced if an EUV/x-ray laser-induced materials erosion (either desorption or ablation) would be engaged in a manufacturing of micro- and nano-structures [1]. In this contribution, we are going to answer the question whether structures with sufficiently small details can be produced in a suitable material directly by intense extreme ultraviolet and x-ray radiation at an acceptable level of quality, with a high yield and aspect ratio. Pulse duration (e-beam- and plasma-based EUV/x-ray sources provide ultra-short and short pulses, respectively) and wavelength (nowadays, short-wavelength lasers cover a wide range of photon energies) effects will be elucidated in both ablation and desorption modes of materials erosion. Special attention will be paid to processes, both thermal and nonthermal, which could blur the structural motif. Their investigation should help to eliminate such sources of imperfections, making possible to create perfectly shaped micro- and nano-structures with sharp edges.

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THE ROAD FROM ENVIRONMENTAL CHEMIST TO RADIATION CHEMIST, A TRIBUTE LÁSZLÓ WOJNÁROVITS

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My Ph.D. work focused on the fate and transport of organic environmental pollutants. Over the years, my research focus moved slowly to photo and radiation chemistry. This was due to the influence of a number of people including László Wojnárovits. I will review how my research has progressed over the last 30 years and how my colleagues and both my graduate and under graduate students influenced that work.

ON THE SUCCESSFUL COLLABORATION BETWEEN HUNGARY AND UNITED STATES ON DEVELOPING SOLID AND AQUEOUS BASED DOSIMETRY SYSTEMS FOR RADIATION PROCESSING

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Over several decades, the collaboration between the radiation chemists of Hungary and the United States has been very productive and yielded outstanding publications and discoveries. Specifically, in the field of radiation dosimetry, this collaboration has enhanced our scientific knowledge in radiation science, and developed new dosimetry systems. This collaboration was led by the late William McLaughlin, David Lewis, László Wojnárovits, A. Kovács, and Erzsébet Takács.

The success of this collaboration yielded the development of radiochromic films (GafChromic DM 1260 and MD 55). These films have been established for broad applications in radiographic imaging, nuclear medicine, and dosimetry for radiotherapy, blood irradiation, insect population control, food irradiation, and industrial radiation processing. They consist of thin, colorless transparent material consisting of thin, colorless transparent coatings of a polycrystalline, substituted diacetylene sensor layer on a clear polyester base. The radiochromic reaction is a solid-state polymerization, whereby the films turn deep blue proportionately to radiation dose, due to progressive 1,4-transadditions as polyconjugations along the ladder-like polymer chains. The pulsed-electron-induced propagation of polymerization has an observed first-order rate constant of the order of 10^3 s^{-1} , depending on the irradiation temperature (activation energy $\sim 50 \text{ kJ mol}^{-1}$). The UV-induced polymerization is faster by about one order of magnitude ($k_{\text{obs}} = 1.5 \times 10^4 \text{ s}^{-1}$). In the case of the electron beam effect, the radiation-induced absorption spectrum exhibits a much slower blueshift of the primary absorption band ($\lambda_{\text{max}} = 675 \text{ nm} \rightarrow 660 \text{ nm}$) on the $10^{-3} - 10^{+1}$ second time scale.

This collaboration has also produced a new dosimeter which can be synthesized in aqueous solution, radiochromic film, and hydrocolloid gel forms. It is based on the radiolytic reduction of colorless tetrazolium salts in aqueous solution to the highly colored formazan dye is a well-known acid-forming radiation chemical reaction. Radiochromic thin films and three-dimensional hydrocolloid gels have been used for imaging and mapping absorbed dose distributions. The high solubility of 2,3,5-triphenyl-tetrazolium chloride (TTC) in alcohols provides a useful liquid dosimeter (45 mM TTC in aerated ethanol) and shows a linear response of absorbance increase ($A_{\text{max}} = 480 \text{ nm}$) with dose over the range 1-16 kGy. The linear molar absorption coefficient (ϵ) for the formazan at the absorption peak is $1.5 \times 10^3 \text{ m}^2 \text{ mol}^{-1}$, and the radiation chemical yield is $G(\text{formazan}) = 0.014 \mu\text{mol J}^{-1}$. The irradiation temperature coefficient is about 0.8 percent per degree Celsius rise in temperature over the temperature range 0-30°C but is much larger between 30 and 60°C.

RADIATION CHEMISTRY OF FROZEN INTERMOLECULAR COMPLEXES: BUILDING NEW SPECIES UNDER EXTREMELY COLD CONDITIONS

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Weak intermolecular complexes can be considered as principal building blocks for the radiation-induced synthesis of complex molecules occurring under the conditions of extremely frozen molecular mobility at cryogenic temperatures (below 10 K). The processes of these kind are of considerable interest for fundamental radiation chemistry and especially important for interstellar chemistry, which is responsible for remarkable molecular diversity of our Universe and origin of life.

This report will outline recent model studies on the mechanisms of the radiation-induced transformations of different types of frozen intramolecular complexes using matrix isolation technique based on combination FTIR and EPR spectroscopy and supported by the high-level *ab initio* calculations. A fascinating chemistry explored in this way typically starts from very simple and highly abundant molecules, such as CO, CO₂, H₂O, HCN, CH₄, C₂H₂, NH₃, C₂H₂, etc., and leads to formation of complex molecules and radicals. The results will be illustrated with the examples related to formation of C,O-containing species [1–4], C, N-containing species [5–7], and more complex molecules containing all the three most important “biogenic” atoms [8, 9]. In addition, possible mechanisms of the radiation-induced formation of aromatic rings from trapped intermolecular complexes will be considered and the first direct experimental evidence for such processes will be presented [10, 11].

The role of ionized and excited states in the radiation-induced evolution of intermolecular complexes and possible involvement of radical-molecular complexes [12] will be discussed. Finally, the most intriguing unresolved issues will be outlined.

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RADIATION CHEMISTRY OF WATER AT INTERFACES IN ELECTRON MICROSCOPY

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The high dose rates typically used in electron microscopy lead to unusual radiation chemistry conditions not normally encountered in traditional water radiolysis. Model calculations show a significant increase in the steady-state concentrations of radicals from water decomposition such as the hydrated electron and the OH radical. In addition, there is the expected increase in molecular products such as H₂ and H₂O₂ along with O₂, while the latter is not produced in any significant quantity in typical electron or gamma radiolysis. Conditions within the beam profile are especially different in electron microscopy. Energy deposition within a small volume leads to severe depletion of both water and solutes, which can lead to unexpected outcomes. Experiments using electron energy loss spectroscopy show that the major oxidizing molecular product from the radiolysis of water ice is O₂ instead of H₂O₂. The presence of an interface can substantially affect the products of water radiolysis. Results will be shown for the radiolysis of water ice at the surface of several different substrates where the observations are different from water ice alone.

KINETICS AND MECHANISM OF RADIATION-INDUCED REACTIONS IN POLYMERS – STUDIES INSPIRED BY THE WORKS OF LÁSZLÓ WOJNÁROVITS

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The scientific works of László Wojnárovits were essential for demonstrating the feasibility of pulse radiolysis for investigating polymerization and other polymer-related reactions, both in liquid systems and in molten neat polymers. He was one of the pioneers in demonstrating that rate constants of radical reactions in polymer systems depend on chain length and substrate concentration, and also that classical kinetics may not be the most adequate model to describe these processes. His broad scientific interests encompassed also radiation synthesis of “smart” polymers, crosslinking of and grafting on polysaccharides, as well as application of radiation-processed polymers in environment protection. Here we will show how these ideas have inspired our own studies over the last three decades [1].

Usefulness of radiation methods to study room-temperature reversibility of polymerization will be demonstrated on the example of methacrylic acid. Triggering depolymerization by irradiation may be one of the contributions of radiation technology to polymer recycling. Determination of propagation rate constant in polymerization will be demonstrated, based on a combination of preparative pulse radiolysis and gel permeation chromatography.

Reaction rate constants are not necessarily constant in polymer chemistry; they can depend on concentration, polymer chain length and reaction time. Non-classical character of polymer radical decay is discussed in terms of intra- and intermolecular reactions. Complementarity of pulse radiolysis and simulations in pinpointing the rate-determining factors is emphasized.

Studies on permanent hydrogel formation while irradiating dilute aqueous solutions of polysaccharides by low doses of ionizing radiation will be briefly discussed.

Finally, we would like to thank László, not only for his inspiring scientific activity and for his friendship, but also for his significant contribution, as the long-time Editor-in-Chief, to the development and constant increase of the scientific level of Radiation Physics and Chemistry, one of the most important scientific journals in our field.

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RECENT DEVELOPMENTS IN QUANTIFYING RADIATION-INDUCED CHAIN COUPLING AND SCISSION IN POLYMERS

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Ionizing radiation induces chain breaking (S, for scission) and coupling (X, for cross-link) which modify the molar mass and the architecture of the irradiated polymers. The statistical models developed by Saito on the one hand, and Charlesby and Pinner on the other, allow for the quantification of radiation chemical yields for scission or coupling between chains, $G(S)$ and $G(X)$, respectively, but when particular conditions are satisfied [1].

Radiolytic effects on polymers possessing a relatively simple structure, such as poly(methyl methacrylate) and poly(butyl acrylate) will be described using the theoretical formalism developed more than 50 years ago, in particular by monitoring of the evolution of the molar masses or the determination of the gel ratio as a function of the absorbed radiation dose. The behavior of random copolymers and mixtures of polymer and reactive additives is more complex to discuss but remains possible in certain favorable cases. The study of a series of copolymers of well-controlled composition made it possible to highlight the influence of physical factors (irradiation temperature with respect to polymer glass transition) and composition (content in repeat units favorable to degradation) on the competition between scission and coupling events [2].

The moisture content is also well known to affect the reactivity of hydrophilic polymers such as polysaccharides. We have further explored the influence of aromatic additives such as benzyl alcohol or cinnamic derivatives in various glucans (starch, maltodextrins, pullulan) which leads to a strong reduction in the response to irradiation measured by the apparent values of $G(S)$ and $G(X)$. The attenuation of reactivity being more marked on $G(X)$, we have observed the formation of gel fraction in notable quantities even for low contents of aromatic additives [3].

Our latest results obtained during the study of the irradiation of poly(hydroxyethyl methacrylate) show how ^1H NMR analysis makes it possible to identify well-identified radiolysis products, to support the proposed reaction mechanisms and to compare the radiolytic yield corresponding to scission determined by size exclusion chromatography or viscosimetry.

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RADIATION PROCESSING – NEW APPROACHES FOR ADVANCED POLYMER-BASED MATERIALS

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Ionizing radiation techniques have consistently proven over the years their potential as a tool for the preparation and functionalization of advanced polymer-based materials.

Applications of new functionalized materials in crucial areas of human activity, are now a reality, constituting an added value in terms of efficiency, comfort and economy. In the last years, an effort has been made to develop new materials and applications in a serious attempt to meet as much as possible the Agenda for Sustainable Development Goals (SDGs) adopted by United Nations (UN).

The Center for Nuclear Sciences and Technologies (C²TN) of Instituto Superior Técnico (IST) has been involved in the development of different polymer-based materials for important practical applications, targeting some UN SDGs. In this lecture, some important and challenging cases will be presented and discussed. Main attention will be given to materials for biomedical applications and for environment preservation, focus on the valorization of waste residues and the recovery of rare earth elements, targeting effective circular economy practices (Figure 1).



Figure 1. A) Dorsal skinfold chamber applied to test mouse, with chitosan-based healing membrane covering an induced wound (burn mimic); B) Anaerobic co-digestion of gamma pre-irradiated macroalgae biomass; C) Nano-magnetic bioadsorbent; Magnetite nano-particles (9 nm) aggregated in a chitosan matrix.

Examples of ionizing radiation techniques applied to CH artefacts (consolidation/conservation) as for functionalization of materials with high demanding thermal and mechanical resistance, will also be discussed.

EFFECT OF GAMMA IRRADIATION POST-TREATMENT ON THE MECHANICAL AND THERMAL PROPERTIES OF MATERIAL OF JETTING-PRINTED PHOTOPOLYMER SAMPLES

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Today, additive manufacturing of polymers is one of the most dynamically developing and expanding polymer product manufacturing techniques. These techniques differ greatly in the raw materials used and the way they are moulded. Of course, these together influence the thickness of the layers that can be created and the connection between the layers. These, and the properties of the polymer itself, determine the quality of the printed product. The material-jetting technique is very advantageous if we want to produce a high-quality product. Such techniques usually use a suitable mixture of oligomers and monomers, resulting in a low achievable layer thickness. The laid layers are polymerised by UV radiation. However, the conversion is not complete. When the next layer is printed, the smaller molecules can diffuse into the previously polymerised layer, and since there is still potential for polymerisation, the layers polymerise together during UV curing, resulting in very good interlayer properties. The polymerisation results in a highly cross-linked thermoset. So, considering the above mentioned aspects, material-jetting is one of the most suitable additive manufacturing techniques to achieve the highest product quality. Good quality comes at a price: this technology is not among the cheapest.

High quality also allows for greater technical content. Therefore, once we have produced a product that is considered expensive, we want to use it as long as possible. Therefore the manufactured products are often subjected to some kind of post-treatment. Their aim is to achieve the highest possible conversion rate. This can be heat treatment or additional UV radiation.

However, the use of ionising radiation is rare, even though, for example, gamma radiation is very effective in increasing the conversion rate and, unlike UV radiation, has a high penetration depth in polymers, resulting in a full-volume effect [1]. In our study, material-jetting samples were treated with gamma radiation with different absorbed doses. In addition to the mechanical properties, we also investigated the structural modification effects of irradiation. It has been shown that gamma radiation can effectively increase the cross-link density, which, in addition to increased mechanical performance, is also manifested in higher glass transition temperatures. The significance of the latter is the broadened thermal application range.

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EXPLORING THE MECHANICAL HYSTERESIS PROPERTIES OF VULCANIZATES CONTAINING GROUND TIRE RUBBER, SURFACE ACTIVATED THROUGH WATER RADIOLYSIS-BASED TREATMENT

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Polymer waste is largely composed of rubber waste, with the significant portion being end-of-life tires. Due to their three-dimensional cross-linked structure, these cannot be processed using traditional processing (extrusion, injection molding) technologies. Therefore, nowadays they are most commonly ground (ground tire rubber, GTR), and then applied in some new matrix (thermoplastic, fresh rubbers, etc.). However, the connection between the phases is often inadequate, leading to poor mechanical properties and limiting their applications. To improve compatibility, various methods have been developed (chemical treatments, devulcanization, etc.), but a new and promising area is the application of ionizing radiation treatments [1], which are increasingly researched fields.

In our previous research [2], we developed a surface treatment method based on water radiolysis. The strong oxidizing agents that appear during the treatment, can attack the surface of the GTR, resulting in active, oxygen containing functional groups, which can facilitate a better connection with the matrix. Improved compatibility significantly enhances mechanical properties, thereby expanding the potential applications of waste ground tire rubber-containing mixtures. However, for certain applications, the dynamic mechanical properties of these materials are also important. These properties not only characterize damping characteristics but also provide information about the connection between phases through hysteresis properties.

In this study, we treated ground tire rubber with gamma radiation at various doses in water medium. We prepared natural rubber-based vulcanizates with the surface-activated GTR. We examined the response of the materials to cyclic loadings in two different ways: using a dynamic mechanical analyzer (DMA) and a universal mechanical testing machine, in tensile testing mode. Subsequently, the results were evaluated, and the radiation's surface-activating effect on mechanical hysteresis was determined, along with the role of the absorbed dose. It was found that radiation treatment resulted in improved compatibility between phases, expanding potential future applications.

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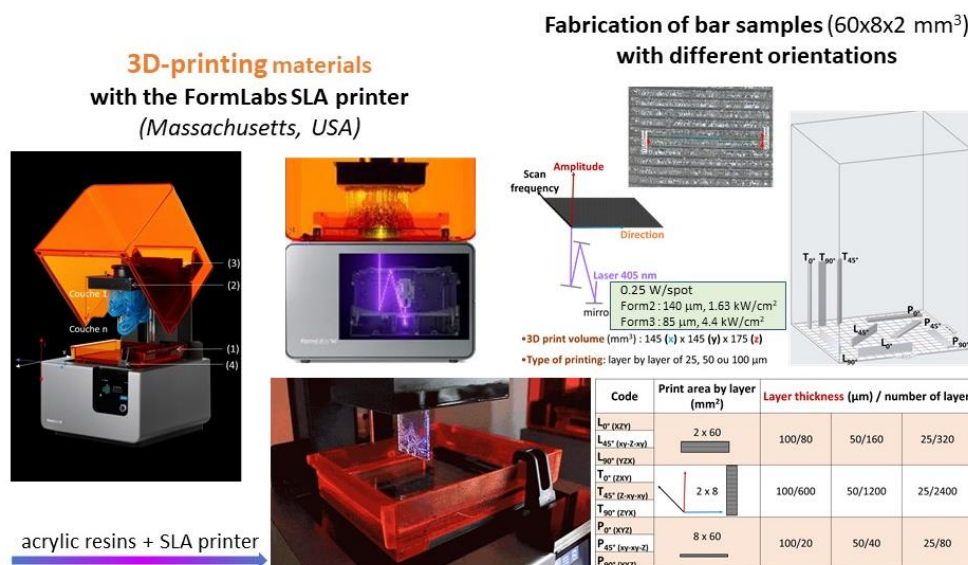
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RADIATION-INDUCED CONSOLIDATION OF THE THERMO-PHYSICAL PROPERTIES OF 3D-PRINTED MATERIALS

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We have recently started exploring the potentialities of high energy radiation processing to consolidation of polymeric objects patterned in the 3 dimensions by techniques such as stereolithography (SLS), and fuse deposition modeling (FDM). 3D printing of polymer materials by photopolymerization under UV-visible radiation or by FDM is based on the successive writing of lines or planar layers with uneven cohesion between the printed domains. In the SLA laser printing method, 3D structures are manufactured, using different printing parameters allowed by the build platform: orientation (L-Longitudinal, T-Transverse, P-Plane at 0 45 90°) or layer thickness (25, 50 or 100 μm). Controlled exposure of polymer-based 3D patterns to high energy radiation can result in changes of molecular weight or in cross-link-density depending on the response of the given macromolecules in terms of scission and covalent bridging between the chains.



We will report here on the EB-induced post-modification of 3D objects printed by SLA using acrylate-based resins, with a focus on the changes in monomer conversion, thermophysical characteristics and tensile properties that occur upon application of increasing doses (up to 100 kGy). The strong influence effect of printing orientation with respect to the long axis of the printed specimens was evidenced. The thickness of the printed layers was also shown to impact the properties of the specimens before irradiation and their evolution after the EB post-treatment. On-going experiments investigate the improvement of fracture toughness of 3D-printed specimens.



RADIATION PROCESSING OF POLYMERS: IS IT STILL RELEVANT? NEW CHALLENGES AND OPPORTUNITIES

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Radiation processing of polymers (mostly polyethylene) was a revolutionary process developed by incredible bright minds, about 70 years ago, as researchers started to submit polymers to radiation and report the occurrence of crosslinking, and other degradation reactions [1,2,3]. Radiation crosslinking was developed along with the new class of polyolefins introduced by the industry based on Ziegler Natta catalyst. Large production of wire and cable, heat shrink products for food wrap and tubing for electrical connections were introduced in the market. Pre-cure of rubber for automobile tires was an important application for automobile radial tires. There are many other applications as curing of inks and varnishes, curing of coatings and fiber-matrix composites. On the radiation induced chain-scission side PTFE and butyl rubber recycling are important applications, and PP modification is a major application for processing control. Radiation sterilization is extremely important and on the contrary of polymer degradation, it does aim to promote polymer modification, but just product safety. The polymer crosslinking and chain scission industries are very mature and deals with relatively low value products. Hydrogels for wound dressing, a relatively new application was developed by Rosiak e collaborators at Lodz [4]. This product was based on the simultaneous crosslinking and sterilization and this technology was transferred for many countries, however its largescale commercialization occurred only in Poland. This application of simultaneous processing steps with radiation sterilization is powerful tool to produce quality and high aggregate value products, decrease production and product cost, decrease energy consumption and decrease waste generated in each operational step. We are going to show new opportunities in the wound dressing industry for rare diseases, and cancer theragnostic and immunotherapy based on radiation processing.

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SYNTHESIS OF NOVEL CO₂ SORBENTS THROUGH RADIATION-INDUCED GRAFT POLYMERIZATION REACTIONS

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Among efforts to ameliorate the worst effects of climate change, carbon capture remains an extensive and growing area of research. Consisting of efforts to selectively extract carbon dioxide (CO₂) from the atmosphere after combustion, current carbon capture efforts are largely segregated into physical and chemical means. We have synthesized various membranes to capture CO₂ from the atmosphere. The synthesis method has been based on radiation-induced polymerization. Direct and indirect radiation induced graft polymerization have been utilized to synthesize these membranes. Primary amines form a key component of a well-studied mechanism for capturing carbon dioxide (CO₂) from the atmosphere. This study comprises a single-step synthesis of a novel sorbent for CO₂ by grafting monomers rich in primary amines to three commercial-grade fabrics: polyethylene terephthalate, high-density polyethylene and nylon 6. An initial evaluation of the sorbency of the chosen monomers, allylamine and butenylamine, qualitatively confirmed their ability to extract CO₂ from the atmosphere. Six novel copolymers, comprised of each of the three fabrics grafted with one of each monomer, were synthesized using radiation-induced graft copolymerization through electron beam irradiation (Figure 1). All fabrics achieved greater grafting with butenylamine compared to allylamine, likely given the closer proximity of the primary amine to the radical on the latter's structure.

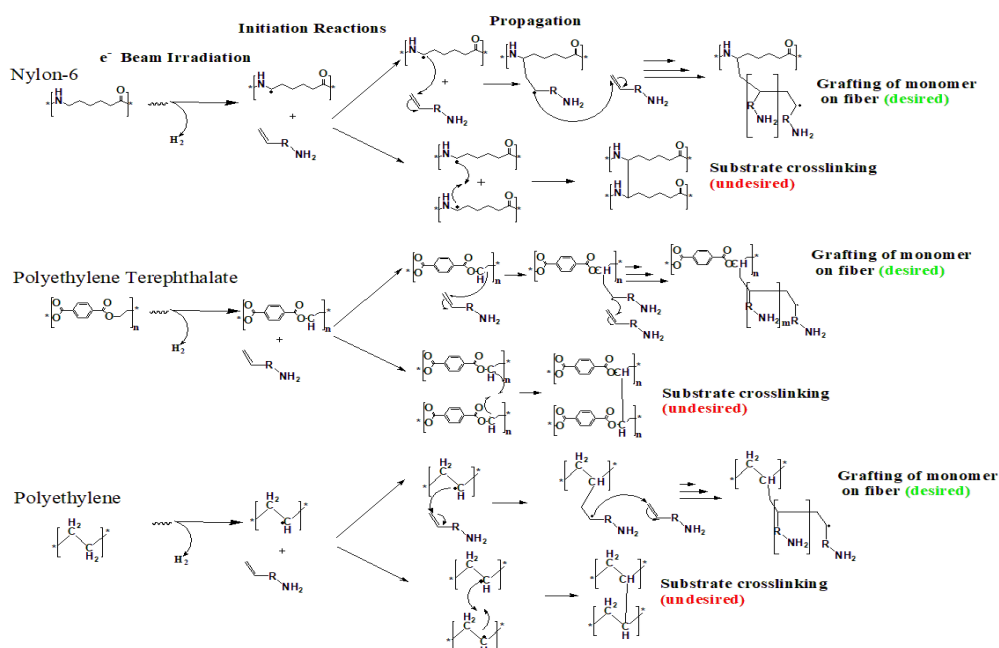


Figure 1. The mechanism of the radiation grafting of vinylamine monomers onto nylon 6, polyethylene terephthalate, and polyethylene.

The synthesis of such complex polymers is a time-consuming process involving considerable trials and errors, countless design of experiments, an infinite chemical space to explore, and last but not least a collaboration across different research groups and organizations. Expediting the discovery of a new design of experiment or configuration that can maximize the desired results such as degree of grafting or carbon capture and minimize undesired outcomes such as side reactions is extremely challenging endeavor. The quantum leap in computational power over the last decade has made the process of material discovery faster and less expensive than ever before. The advent of cloud technology, faster computer processors, and advanced machine learning algorithms have enabled data-driven scientific experiments. Bayesian optimization and gaussian processes have shown promising results on how to set up an experiment and where to push the experimentation envelop offering assurance on obtaining meaningful outcome at a fraction of cost.

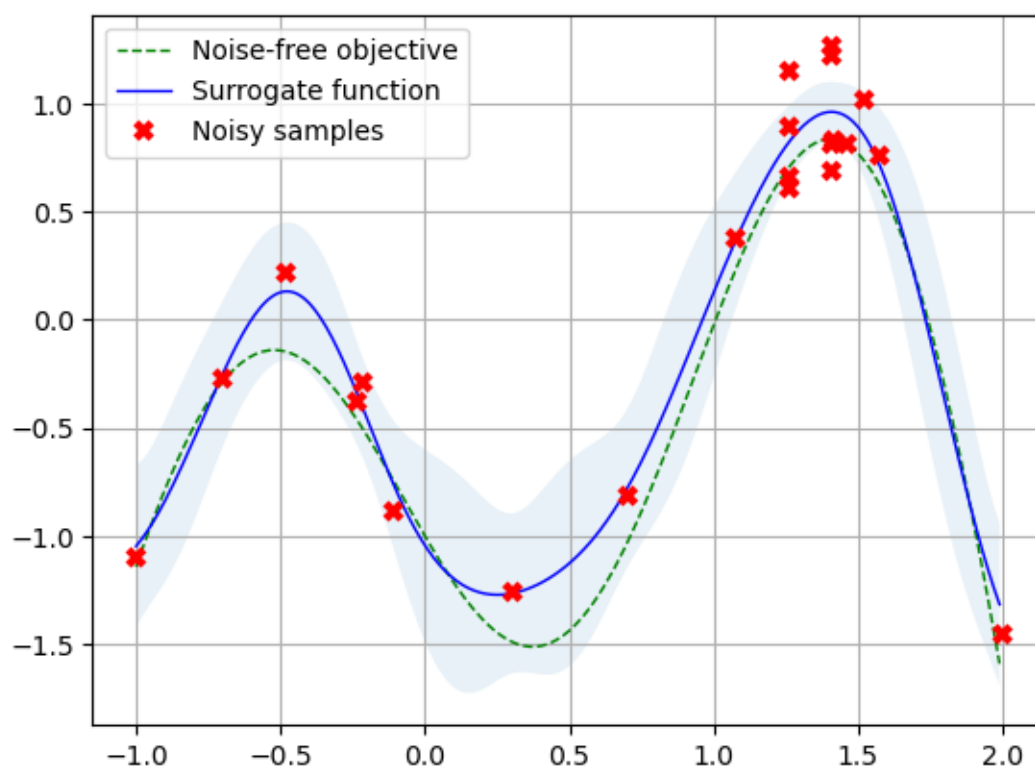


Figure 2. The hidden or unknown objective function (noise-free) that maps the input to the output of experiments, the surrogate function approximated by gaussian process regressor based on generated sample points (red crosses) which in turn their sampling locations were decided by Bayesian optimization to maximize the property of interest (degree of grafting), and the 95% confidence interval in (sky-blue).

DEGRADATION OF A STEROID ANDROSTENEDIONE IN AQUEOUS SOLUTION USING IONIZING IRRADIATION

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Endocrine disrupting chemicals (EDCs), being recognized as one of the most crucial groups of emerging contaminants, have recently attracted growing concerns globally [1]. Among them, the steroid compounds pose significant risks due to their persistent endocrine-disrupting and carcinogenic properties [2]. This study focused on the degradation of a steroid hormone, androstenedione (AD) in aqueous solutions using gamma radiation. With an initial AD concentration of 10 mg/L, the removal percentage of AD approached nearly 100% when the absorbed dose reached 0.6 kGy. The degradation rate of AD is minimally impacted within a pH range of 4.1 to 9.4, but significantly slows down in strongly alkaline conditions at a pH of 11.0 (Figure 1). The primary mechanism for AD degradation under gamma irradiation was identified as oxidation by OH^\cdot , with reduction by e_{aq}^- also playing a contributory role. The presence of dissolved organic compounds, including glucose, peptone, sodium dodecyl benzene sulfonate (SDBS), and starch, has been observed to significantly inhibit the decomposition of AD. In contrast, hydrophobic substances like soybean oil have a negligible effect. AD degradation through γ -irradiation demonstrates a robust resistance to interference from ions such as Cl^- , PO_4^{3-} and SO_4^{2-} at concentrations ranging from 0.001 M to 0.1 M. However, the presence of CO_3^{2-} and NO_2^- ions exhibits a strong inhibitory effect on the degradation process. The intermediates of AD degradation were identified through analysis of Ultra-High Performance Liquid Chromatography (UHPLC) Q-TOF Mass Spectrometry (MS) and density functional theory (DFT) calculation. Overall, these results highlight ionizing radiation as a promising method for the degradation of AD in water matrices.

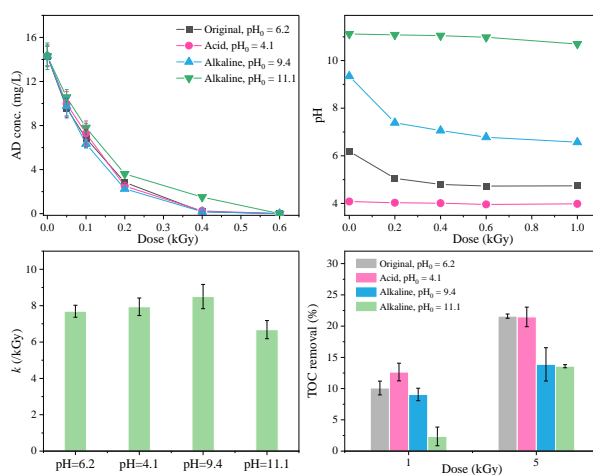


Figure 1. The impact of initial pH on AD degradation under γ -ray irradiation

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DEGRADATION OF TETRACYCLINE IN AQUEOUS SOLUTION BY ELECTRON BEAM: KINETICS AND DEGRADATION MECHANISM

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Tetracycline (TC) is a common human and veterinary antibiotic that is widely detected in waters and natural waters. The traditional methods have some limitations for the removal of tetracycline. Therefore, the electron beam degradation of TC was explored systematically in this study. After 4 kGy irradiation, 50 mg/l of TC could be degraded by 85%. The effects of pH, inorganic anions (Cl^- , HCO_3^- , NO_3^- , CO_3^{2-} , SO_4^{2-}), humic acid, H_2O_2 , $\text{Na}_2\text{S}_2\text{O}_8$, gas and different water bodies (pure water, tap water, groundwater, river water) were investigated. The results showed that the degradation effect of TC was better in acidic environment. Inorganic anions and organic matter in water inhibited the degradation of TC to varying degrees. H_2O_2 , $\text{Na}_2\text{S}_2\text{O}_8$ and N_2O significantly promoted the degradation of TC. The degradation intermediates were also determined and the TC degradation pathway was explored. In summary, electron beam irradiation could be applied to remove TC effectively in aqueous solution.

Acknowledgement:

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GAMMA RADIATION/H₂O₂ TREATMENT OF SELECTED EMERGING CONTAMINANTS: EXPERIMENTAL AND THEORETICAL EVALUATION

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Emerging contaminants are pollutants that can have a lethal impact on the endocrine systems of humans and wildlife, even when present in trace quantities ($\mu\text{g/L}$ or ng/L). Since traditional treatment methods are ineffective at removing these pollutants from the environment, their presence has become a serious problem. The study has demonstrated the application of gamma radiation/H₂O₂ to eliminate selected organic contaminants (ketoprofen, KET; diclofenac, DCF; ibuprofen, IBF; diethyl phthalate, DEP; bisphenol-A, BPA; triclosan, TCS) from real wastewater effluent. The gamma irradiation at doses of 0-50 kGy was carried out by using a ⁶⁰Co irradiator (Ob-Servo Sanguis) installed at Nuclear Energy Research Institute in Ankara, Türkiye. In order to investigate the effect of H₂O₂ on the removal efficiency (RE) of selected contaminants, different H₂O₂ concentrations (0.1%, 0.5%, and 1.0%) were tested. The target contaminants were analyzed using LC-ESI-MS (Waters Alliance 2695, Waters Micromass ZQ 2000). It was found that IBU, TCS, and BPA were efficiently removed (>86%) at a dose of 10 kGy. However, higher doses were required to eliminate DCF (20 kGy for ~93% RE), KET (30 kGy for ~79% RE), and DEP (30 kGy for ~83% RE). On the other hand, the addition of 0.5% H₂O₂ to wastewater samples followed by irradiation at 10 kGy significantly increased the RE% of the compounds (KET and DCF ~87%, IBF ~92%, TCS and BPA below the limit of detection), with the exception of DEP (~55%). The use of ionizing radiation to decompose contaminants in water samples is based on the reactions of the pollutants with the reactive species formed through the radiolysis of water. It is known that hydroxyl radicals ($\cdot\text{OH}$) behave as electrophiles, while hydrated electrons (e_{aq}^-) act as nucleophiles in the reaction with organic molecules. However, the reaction of target pollutants with these active species and their decomposition depend on the specific chemical structures of these molecules. The computational study can be exploited to characterize the site-specific reactivity parameter towards the electrophilic and nucleophilic attacks namely for $\cdot\text{OH}$ and e_{aq}^- . For this purpose, Density Functional Theory (DFT) with Becke's three-parameter exchange function, the Lee-Yang-Parr nonlocal correlation functional (B3LYP), and a 6-31G (d, p) basis set executed via the Gaussian 09 software have been applied to examine the global and local chemical reactivity parameters of the target molecules.

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APPLICATION OF ELECTRON BEAM FOR WASTEWATER TREATMENT IN CHINA: CURRENT STATUS AND PROSPECTS

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Abstract –The presentation will introduce the basic principles, characteristics, and technological advantages of electron beam irradiation for the treatment of wastewater, as well as the research and development process of the author's research group in this field since 2003. The current application status of electron beam irradiation technology for industrial wastewater treatment will be introduced in detail, including practical projects for treating dyeing wastewater, chemical wastewater, coking wastewater, pharmaceutical wastewater, hospital wastewater etc., and the application prospects of this technology are looked forward.



Figure 1. The application of electron beam radiation for the treatment of dyeing wastewater in Jiangmen city, Guangdong province, China

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ELECTRON BEAM TECHNOLOGY FOR THE HIGH CONCENTRATED UDMH SOLUTION TREATMENT

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Unsymmetrical dimethylhydrazine (UDMH) is an excellent propellant which is often used in the aerospace industry. However, due to its high toxicity, UDMH may pose a huge safety risk to the surrounding environment and field workers. In this study, a process of electron beam (EB) irradiation treatment of UDMH without adding any chemicals was developed. The influence factors such as pH, concentration of UDMH and different absorbed doses on the effects of UDMH degradation and chemical oxygen demand (COD) removal were investigated. The present results showed EB process could effectively degrade UDMH and COD in the wastewater and the removal efficiencies of both UDMH and COD increased with the increase in EB absorbed dose. When the initial concentration of UDMH was 40300 mg/L and the absorbed dose achieved 1200 kGy, the removal efficiencies of UDMH and COD were 99.35% and 75.47%, respectively. In addition, for UDMH wastewater with an initial concentration of 12247 mg/L, UDMH could be completely removed and COD could be reduced to less than 50 mg/L by 400 kGy irradiation coupled with electrochemical oxidation for 7 h. This study provides an alternative process, especially for emergency treatment of high concentration UDMH wastewater.

ELECTRON BEAM RADIATION COUPLED WITH FLOCCULATION PROCESS FOR ADVANCED TREATMENT OF COKING AND DYEING WASTEWATER: PERFORMANCE AND SYNERGISTIC EFFECTS

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Advanced treatment of industrial wastewater is a tough problem in the field of wastewater treatment. In this study the electron beam radiation coupled with flocculation process was firstly developed and investigated for the advanced treatment of industrial wastewater. Three different coupled processes were studied, i.e. electron beam radiation followed by flocculation process (EBF), flocculation followed by electron beam radiation process (FEB), and simultaneous electron beam radiation and flocculation process (SEBF). It was found that different processes had various performances in the removal of targeted organic pollutants. For humic acid, FEB with poly aluminum ferric chloride (PAFC) as flocculants showed the best synergistic effect at 10 kGy, in which the removal efficiency of humic acid was 95.2%, while SEBF exhibited the inhibition effect under all the conditions. For rhodamine B, EBF with PAFC had the highest synergistic effect at 10 kGy, in which the removal efficiency of Rhodamine B was 87.4%. For phenol, SEBF with PAFC as flocculants showed the highest synergistic effect at 10 kGy, in which the phenol removal efficiency was 64.2%. The transformation of organic pollutants, such as the polymerization was the main reason for the synergistic effect of EBF, while the dissolved iron ions and the enhanced oxidation made major contribution to the synergistic effect of FEB, and the structural change of flocculants and the transformation of organic pollutants during the process of electron beam radiation was mainly responsible for the synergistic effect of SEBF. EBF showed better performance in COD removal of actual coking and dyeing wastewater than FEB, indicating that electron beam radiation could promote the flocculation effect. Considering the operation procedure and treatment cost comprehensively, EBF with PAFC is recommended for the advanced treatment of actual coking and dyeing wastewater. This study could provide a novel and effective method for the advanced treatment of industrial wastewater.

PREDICTING DEGRADATION MECHANISMS IN LITHIUM BISTRIFLIMIDE “WATER-IN-SALT” ELECTROLYTES FOR AQUEOUS BATTERIES

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Aqueous electrolytes, studied since the 1990s, are a way to solve the current problems of Li-ion batteries in terms of safety, cost and environmental impact. However, their energy density is limited by the narrow thermodynamic stability window of water (1.23 V). The concept of concentrated aqueous electrolytes has completely changed this vision with the discovery of the so-called water-in-salt electrolyte (WISE), obtained by dissolving a large amount of salt in water. These electrolytes can be depicted as few water molecules surrounded by cations and anions forming ion pairs. This change of solvation structure compared to standard electrolytes increases the electrochemical stability window. For example, using 20 molal (molality: m , moles per kg) lithium (bistrifluoromethanesulfonyl(imide)) (LiTFSI) aqueous solutions, a stability window of 3 V can be reached [1]. In this context, unraveling the degradation properties of the aqueous electrolyte itself is paramount and motivated the present study.

We use here radiolysis to exacerbate in a short time the degradation mechanisms [2] of concentrated LiTFSI-based aqueous solutions [3]. We show that the nature of the degradation species strongly depends on the molality, with degradation routes driven by the water or the anion at low or high molalities. The main aging products are consistent with those observed electrochemically, while radiolysis also allows to unravel minor species, giving a glimpse of the long-term (un)stability of these electrolytes. Water chemistry drives the degradation process at low molality, resulting in high H₂ production, modest CO₂ production, and other gases containing hydrogen atoms. At high molality, the anion decomposition imposes the aging behavior, causing a significant reduction in H₂ production.

Picosecond pulse radiolysis at the ELYSE platform was also used to follow the fate of the solvated electron in these WISEs. The increase in molality causes a corresponding increase in the solvation time of the solvated electron. In a 20 m solution, solvation was completed within 400 ps, with a characteristic time of 55 ps. Moreover, the shift of the spectrum of the solvated electron to lower wavelengths when molality increased denoted an increase in the number of Li⁺ cations interacting with the solvated electron. Degradation mechanisms with the effect of the molality of the salt will be presented and discussed during this presentation.

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IAEA’S ROLE IN THE DEVELOPMENT AND EMERGING TRENDS ON RADIATION TECHNOLOGY APPLICATIONS

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Radiation technologies have emerged as powerful tools in industry, agriculture, and scientific research.

While numerous innovations and achievements in radiation sciences have been recognized, there remains ample opportunity to comprehensively assess their status in academia and industry, as well as their readiness to confront future challenges.

The International Atomic Energy Agency (IAEA) is dedicated to accelerating and expanding the role of atomic energy in promoting peace, health, and prosperity worldwide. To support its Member States the IAEA actively assists radiation scientists in addressing issues pertinent to areas where radiation technology can make a significant impact. This includes:

- Environmental applications (such as wastewater treatment, greenhouse gases mitigation, biomass valorization and tackling plastic pollution through initiatives like NUTEC Plastics);
- Development of advanced materials (functionalized materials, nanomaterials, etc.), and;
- Cultural heritage preservation.

The IAEA commitment to support non-power nuclear applications in its Member States, encompasses facilitating the development and adoption of radiation science and technology through the existing IAEA mechanisms. This support entails initiatives at national, regional, and global levels aimed at performing R&D activities, strengthening capacity building, and implementing proven industrial applications that yield socio-economic benefits within Member States.

LOW-CARBON RADIATION CHEMICAL PROCESSES OF PRODUCTION OF OLEFINS FROM OIL FRACTIONS

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In traditional petrochemical and oil refining technologies, organic fuels (such as natural gas, fuel-oil, etc.) are burned as an energy source to support chemical processes at high temperatures ($T > 700^{\circ}\text{C}$). Oxygen is used from the atmosphere, and greenhouse gas -CO_2 is emitted instead. For instance, 450 million tons of carbon-dioxide emissions occur in ammonia synthesis and 300 million tons in petrochemical processes. Moreover, because these processes occur at high temperatures, the selectivity of the main product is low due to deep destructive processes. Stimulating these processes using physical methods can lower the required temperatures and limit carbon emissions.

This article examines the processes of obtaining olefins in energy-intensive chemical processes stimulated in petroleum hydrocarbons by ionizing radiation. Radiation-chemical processes were conducted using model hydrocarbons – n-heptane, n-decane and n-pentadecane and the results were approved on oil fractions $F_1 = 162\text{-}400^{\circ}\text{C}$ and $F_2 = 230\text{-}310^{\circ}\text{C}$ under extreme conditions, using high dose rates (2300W/kg). The experiments were conducted in stationary and flow conditions at the MRX- γ -30, Co-60 isotope γ -rays, and ELU-4, ELIT-1 electron accelerators at the Institute of Radiation Problems of the Ministry of Science and Education of Azerbaijan. The parameters varied within the following ranges: dose rate $P = 2.5\text{-}300\text{ kGy/hour}$, absorbed dose $D = 0\text{-}300\text{ kGy}$, temperature $T = 20\text{-}550^{\circ}\text{C}$.

The maximum yield of olefins is achieved at temperatures of $T = 375\text{-}400^{\circ}\text{C}$ with a dose value of $D = 30\text{ kGy}$ and reaches 77.5 % for the product. At higher temperatures and dose rates, the selectivity and, in some cases, the radiation-chemical yields of olefins decrease due to deep destructive processes and recombination of active particles. The optimal values of dose rate and temperature depend on each other. A kinetic model of radiation-thermal processes occurring in this type of systems is proposed to determine these dependencies. The main condition is that the radiation component exceeds the thermal component, and the reactions proceed in a chain mode, where breakdown reactions dominate over recombination reactions. This condition establishes a semi-empirical dependence between the optimal dose rate and temperature. Approximate technical and economic indicators of the conducted processes were calculated. Three parameters were calculated: efficiency of energy conversion, productivity and economic efficiency. A conventional comparative analysis has shown that, with appropriate energy sources and technological parameters, it is profitable to obtain relatively expensive olefins, including α -olefins, using these methods.

TRANSIENT PROCESSES FOR THE RADIOLYSIS OF DIAMIDE PHENANTHROLINE IN 1-OCTANOL

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Diamide-phenanthrolines (DAPhen) are promising in group separation of actinides in spent nuclear fuel reprocessing. In this work, the radiolysis mechanism of DAPhen was studied using pulse radiolysis technique. In the 1-octanol solution containing N^2,N^9 -diethyl- N^2,N^9 -ditotyl-1,10-phenanthroline-2,9-diacarboxamide (ETD, of which the structure is shown in inset in Figure 1c), solvated electrons (e_{sol}^-) showed a broad absorption band around 650 nm (Figure 1a). The decayed followed 2nd-order kinetic model, of which the reaction rate constant between ETD and e_{sol}^- was calculated to be $k_{ETD-e} = 1.5 \times 10^9 \text{ L mol}^{-1} \text{ s}^{-1}$. The reaction is diffusion controlled due to the high viscosity of 1-octanol (Figure 2a). In the mixture of 1-octanol and HNO_3 aqueous solution (3 mol L^{-1}), e_{sol}^- were efficiently scavenged by H^+ and NO_3^- dissolved in 1-octanol (Figures 1b and 1c). The absorbance at 375 and 660 nm show a slow formation process with the same rate, which should be accordingly attributed to the reaction between ETD and hydroxyoctyl radicals ($\text{C}_7\text{H}_{15}\cdot\text{CHOH}$). The reaction rate constant was then estimated to be $k_{ETD-R\cdot OH} = 2.2 \times 10^8 \text{ L mol}^{-1} \text{ s}^{-1}$ (Figure 2b). HPLC–MS measurement of the steady-state radiolytic products demonstrated that ETD was easier to be radiolyzed *via* the reaction with e_{sol}^- . Meanwhile, the concentrated HNO_3 in spent nuclear fuel reprocessing can be scavenge e_{sol}^- , and thus protecting ETD.

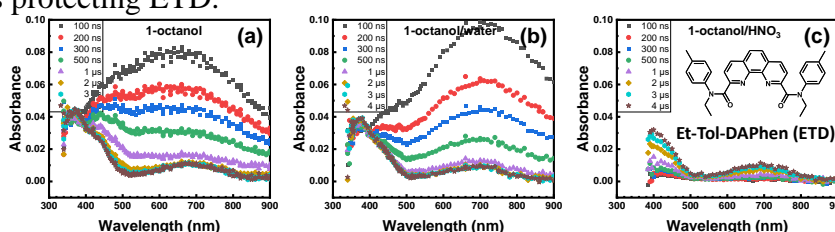


Figure 1. The UV–Vis absorption spectra of ETD in (a) 1-octanol, (b) mixture of 1-octanol and water, as well as (c) mixture of 1-octanol and HNO_3 aqueous solution (3 mol L^{-1}).

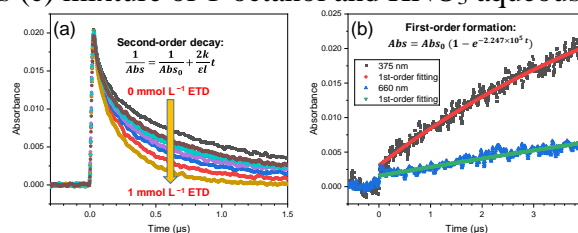


Figure 2. Evolution of the absorbance in the fast decay process in Figure 1a (650 nm) and slow formation process in Figure 1c (375 and 660 nm).

LABORATORY ASTROCHEMICAL STUDIES ON ION-IRRADIATED ICE ANALOGUES FOR THE JUICE MISSION

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Jupiter's plasma environment is one of the most intriguing plasma laboratories in our Solar System. The whole system is fed by plasma sources predominantly from within the magnetosphere with contributions from outside. The volcanic moon Io is the strongest internal source with smaller contributions from Europa and possibly from other moons, as well as the ionosphere of Jupiter [1]. ESA's Jupiter Icy Moons Explorer (Juice) mission is to explore Jupiter's complex environment in depth. Embedded in Jupiter's inner magnetosphere, icy moons interact strongly with the surrounding plasma. Voyager and Galileo data have shown that these moons are constantly bombarded by electrons and energetic ions (H^+ , C^{n+} , O^{n+} and S^{n+}). The effect of this intense irradiation on the ice is the main driver of the formation of thin atmospheres and may be crucial in shaping the properties of the ocean beneath the icy crust. However, the details of the surface processes and their impact on the environment are poorly understood. In the framework of the Europlanet 2024 RI collaboration, these processes, which may be essential for the origin of life, are simulated in the laboratories at ATOMKI to understand them in detail [2]. Particularly, we have investigated the radiolytic sulphur chemistry arising as a result of the implantation of reactive sulphur ions into various oxygen-bearing molecular ices [3].



Figure 1. The Ice Chamber for Astrophysics/Astrochemistry (ICA) at ATOMKI

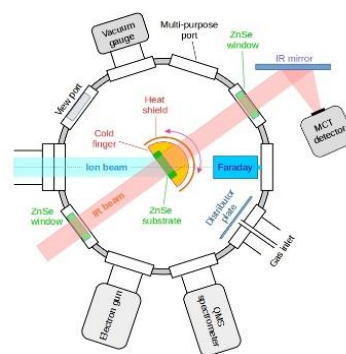


Figure 1. Schematics of ICA.

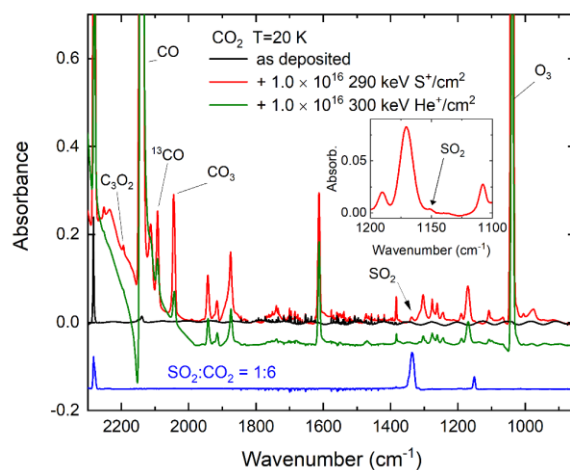


Figure 2. Infra-red absorption spectra of S^+ irradiated CO_2 ice.

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GGAG:Ce³⁺@SiO₂-RB COMPOSITE FOR RADIODYNAMIC THERAPY

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Republic

Cancer is one of the leading causes of death worldwide for people aged under 70 years. The goal of all cancer treatments is to maximise the effect on cancer cells while minimising side effects and damage to healthy tissues. Malignancies with poor treatment prognosis represent the greatest challenge. Radiodynamic therapy (RDT) is a medical treatment based on a combination of classic photodynamic therapy and the use of X-rays to reach deep-seated tumours. The principle of RDT is based on the conversion of the energy of X-rays into singlet oxygen. The advantage of this approach is the significant synergistic effect of this combination.

In this work, composite nanoparticles GGAG:Ce³⁺@SiO₂-RB is investigated. This multicomponent composite contains a scintillating core of Gd₃Ga_{2.5}Al_{2.5}O₁₂ garnet doped with cerium (GGAG:Ce³⁺). The Ce³⁺ dopant is chosen so that the radioluminescence emission spectrum of the core overlaps with the optical absorption spectrum of the photosensitiser used. To ensure the chemical stability of the core, it is encapsulated in a silica layer (@SiO₂). The photosensitiser Rose Bengal (RB) is chosen for functionalization and is grafted onto the silica layer. This composite nanomaterial has a good potential for singlet oxygen production by X-rays. The prepared material was characterised by various methods (such as XRPD analysis, size measurement by DLS, radioluminescence and photoluminescence measurement), tested for singlet oxygen production, and evaluated for dark toxicity in *Saccharomyces cerevisiae*.

The use of chemical probes for singlet oxygen detection offers a much simpler alternative to the direct measurement of its phosphorescence; however, one needs to be careful, especially during X-ray-induced generation of singlet oxygen, of the possible reactivity of the probe towards other reactive oxygen species. In this work, an anthracene derivative, 9,10-anthracenediyl-bis(methylene)dimalonic acid (ABDA), was used as a chemical probe for singlet oxygen. Previous experiments with this probe under X-ray irradiation have shown that it is only possible to use it in aqueous solutions if it is accompanied by alcohols as hydroxyl radical scavengers; as the probe is soluble in ethanol, it seems to be a promising solvent for the evaluation of singlet oxygen production.

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THE ROLE OF IRRADIATION IN THE DEVELOPMENT OF ECO-FRIENDLY ACTIVE FOOD PACKAGING

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The global production of plastic (1.8 billion tons) is an important source of greenhouse gas release (GHG) (54.6 billion tons of CO₂ eq.). Some of these multi-material barrier type plastic waste has been a pressing problem because of their persistence and non-recyclability. Producing conventional plastics consumes 65% more energy and emits 30-80% higher GHG than bio-based polymers. It is also known that 50% of plastics are used for food packaging and 66% of food contamination is caused by faulty packaging. More than 30 % (~ 2.5 billion tons) of food are wasted every year and worth \$230 billion. According to the United Nation environment program, 10% of GHG emissions are associated with food loss.

The development of active packaging is a good approach to reduce food waste. Therefore, there is an urgent need to replace them by low GHG, biodegradable, compostable and recyclable food biopackaging films (LGHGF). According to the National Research Council of Canada, biopolymers could reduce the GHG emission by 16-30% with 3.4-4.0 kg CO₂ eq/kg, compared to polyethylene with 4.8 kg CO₂ eq/kg.

Agricultural and food byproducts and wastes are good energy reserve and are the cheapest polymers available in nature. These inexpensive polymers and LGHG footprint wastes can be used for the development of LGHGF. However, the challenge is to improve the mechanical, the water resistance and obtain the required barrier properties of these films. Food and agricultural by-products could be also of great economic and environmental potential as sources of low-cost natural bioactive compounds with antimicrobial and antioxidant properties.

Irradiation can be used to induce structural changes in natural polymers to enhance their functional properties and biocompatibility. The use of ionizing radiation to modify/functionalize/crosslink such polymers and their functional components will be highlighted. These modifications can be extended to the development of active food packaging, based on the different reactions that can be conducted and implying the contribution of polymer matrix as well as the other film components among which are filling agents, grafted monomers, and other compatibilizers, cross-linkers, and bioactive compounds. Radiation can be used to produce nanoparticles, or to disperse them in polymers. Grafting nanoparticles or natural antimicrobial compounds as functional components into polymer bulk can permit to form bio active-nanocomposites based-films. The focus of this presentation is to demonstrate how ionizing radiation can be combined with the recycling of natural materials such as biopolymers and bioactive phytochemicals to create advanced active eco-friendly food packaging through the concept of hurdle technology.

ELECTRON-BEAM REINVENTING BIO-BASED POLYMERS AND SUSTAINABLE MATERIALS TO FUNCTIONAL MICRO/NANOSTRUCTURES FOR NET-ZERO INDUSTRY

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Under a climate crisis, there has been increasing interest in the sustainable bio-based polymers, bioplastics, and biochemicals, e.g., cellulose, chitosan, fibroin, poly(lactic acid) (PLA), plant oils derived from renewable resources. Using electron beam (EB) for reinventing bio-based materials to value-added products meets the current national and global eco-friendly concepts, i.e., bio-, green and circular (BCG) economy and net-zero emission. Many fundamental radiation-induced reactions (e.g., oxidation-reduction, degradation, crosslinking, polymerization, and grafting) become important green processes for synthesis and modification of functional bio-based polymeric materials through the reactive intermediate radiolysis species (e.g., $\cdot\text{OH}$, $\text{H}\cdot$ and e_{aq}^-) including simultaneously generated macroradicals. The presentation will summarize the invention of numerous value-added bio-based materials in micro/nanostructures with different functions using high energetic radiation induced chemical reactions. The current progress in micro/nanostructures and their applications encompass cellulose microcomposite hydrogels/adsorbent [1], chitosan/PLA nanocomposite [2], chitosan amphiphilic nanoparticles [3], pH-responsive chitosan interpolymer complex nanoparticles [4], fibroin polypeptide nanogels [5], nanofibers/composite nanofibers [6], and micro/nanostructured surface for bio-coating/inks [7-9]. The details in molecular and reaction design, mechanisms and chemical structures elucidation, micro/nanostructures characterizations, material performance verification for each application are included in the presentation. The optimized parameters (e.g., dose, dose rate, macromolecular system) affecting radiation-induced chemical reactions and macromolecular structures have been crucial keys for successful invention and paving the way to greener process design.

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EFFECT OF IONIZING RADIATION ON THE ACTIVITY OF ENZYMES

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It has long been known that the effect of ionizing radiation on enzymes and enzymatic systems, which are responsible for most cellular functions, leads to chemical alterations in the structure of the enzyme molecules and, as a subsequent result, either to an inhibition or to activation of their catalytic properties [1,2]. Hence, it is important for the understanding of the molecular and kinetic mechanisms of action of ionizing radiation on these systems to find suitable experimental protocols and kinetic models applicable to specific enzymes and their substrates. In this study, first we propose an experimental protocol, which includes using a medical linear accelerator complex that provides unique experimental conditions for homogeneous irradiation of enzyme solutions and precise dosimetric calculations, measurements, and verification of the applied doses of high-energy photon ionizing radiation to study the changes in the catalytic activity of the enzyme invertase, using sucrose as substrate. It was found that with increasing the radiation dose applied the invertase activity decreased. From the experimental data and following the MichaelisMenten kinetic model we determined the values for the kinetic constants K_m and V_{max} for the reaction catalyzed either by native or irradiated invertase and made conclusions for the possible changes.

Second, we propose a specific experimental approach to study the effect of ionizing radiation on the catalytic action of the neurotoxin *Vipoxin* (a dimeric protein complex composed of an active phospholipase A₂ (PLA₂) and an inactive component) on the phospholipid substrate using as a model system – the Langmuir monolayer. Because the properties of the phospholipases are strongly dependent on the structural organization of the phospholipids, in our approach, the *Vipoxin* was dissolved in buffer solution and irradiated with various doses from 0.1 to 10 Gy, and afterwards using a modified Langmuir trough, the surface area change of the phospholipid monolayer was measured in real time. This allowed us to obtain the dependence of the catalytic action of the neurotoxin at a certain surface pressure and to determine the basic constants of the enzyme reaction. It was found that the higher radiation doses increased the activity of *Vipoxin*, which led us to the assumption that it was probably due to dissociation of the *Vipoxin* dimeric complex.

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OPTIMIZATION OF CELLULOSE AND ALPHA CELLULOSE SOLUBILITY IN SODIUM HYDROXIDE

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Cellulose, the most abundant natural polymer on earth, has been limited in its application to industrial processes due to its low solubility. It is a difficult compound to dissolve largely due to its intra- and intermolecular hydrogen bonding [1]. While not soluble in water, cellulose is soluble in some ionic liquids that have the ability to break the hydrogen bonds that help cellulose retain its crystalline form [2]. However, ionic liquids are not environmentally friendly and are largely made up of organic compounds with high toxicity and low biodegradability [3]. Sodium hydroxide can be used in place of ionic liquids because it fully dissociates, creating ions, that will interfere with hydrogen bonding [4]. Ionizing radiation has been shown to break the 1-4 glycosidic bonds in glucose, providing more available surface area per gram, increasing solubility [5,6]. The goal of this study is to maximize solubility of cellulose and alpha cellulose utilizing techniques that have a smaller environmental footprint than ionic liquids. This study examines the effects of two variables on cellulose solubility: sodium hydroxide concentration and ionizing radiation dosage.

This study adapted the Technical Association of the Paper and Pulp Industry (TAPPI) method T 235 for Alkali solubility of pulp at 25 °C. The TAPPI T 235 was designed for pulp extraction and dissolution of degraded cellulose [7]. This method used a similar concentration scheme but excluded the pulp extraction in favor of comparing cellulose dissolution before and after irradiation. This research utilized the Co-60 source at National Institute of Standards and Technology (NIST) to irradiate the samples at 0, 100, 250, 500, 750, and 1000 kGy. Samples of 0.75 g of were dried for 24 hours at 102 °C ± 0.5 °C in a Gallenkamp Microprocessor Controlled Oven (model 1350FM), then soaked in 30 mL of various concentrations of NaOH that included 0% (deionized water), 1%, 7%, 12%, 21.5%, and 25% by weight for 3 hours under constant stirring with a magnetic stir plate (VWR Standard Multi-position Stir Plate). After stirring, the remaining insoluble cellulose was filtered off with a Buchner Flask and a coarse 30 mL sintered glass filter and washed with distilled water. The amount of soluble cellulose was determined by titration.

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SINGLE MOLECULE APPROACHES TO STUDYING RADIATION-INDUCED LESIONS IN DNA

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Ensemble approaches to measuring chemical interactions can mask subtle nuances that can be uncovered by examining reactions at the single-molecule level. This is especially true in radiochemistry, where highly-reactive short-lived oxidizing agents are generated in clusters around discrete particle tracks. While the field of single-entity sensing is often associated with fluorescence, the last 30 years has seen a rapid development of sensors, particularly biosensors, that rely on nanoscopic cavities in proteins or dielectric materials.

The emergence of nanopore sensors as a tool for single-molecule analysis—in particular for the study of biological molecules such as DNA—provides powerful new tools for understanding radiation-induced lesions at the scale of individual molecules.

We are applying this tool to solve an acute measurement problem in radiotherapy, where methods to measure biological dose with precision and throughput at the cellular level are urgently needed to support radiotherapy across low-LET and high-LET beams in existing treatments as well emerging treatment modalities, such as FLASH therapy. We present a nanopore approach for measuring radiation-induced DNA lesions and present a roadmap for the development of a precision measurement of DNA damage to personalize radiotherapy treatments. To measure radiation induced lesions, we fabricate pores with ≈ 10 nm diameter pores in silicon nitride membranes or laser-pulled quartz nanopipettes, and measure ionic current driven by an applied electric field. As DNA is driven through the pore, the current is interrupted in a resistive pulse, which is characterized to measure properties of the molecule, including length and flexibility. By assessing the extent of double-strand lesions, we provide a direct measure of acute damage to DNA relevant to assessing relative biological effectiveness (RBE) of ionizing radiation. The talk will conclude with a prospectus for the further development of this tool as a clinically deployable sensor and as a fundamental research tool.

GAMMA RADIATION: A TECHNOLOGY TO ENHANCE THE EXTRACTABILITY OF BIOACTIVE COMPOUNDS FROM OLIVEWASTES FOR FOOD APPLICATIONS

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Olive pomace is an environmentally detrimental waste from olive oil industry that contains a variety of bioactives, such as phenolic compounds in relevant amounts. In this work, ionizing radiation was applied as a pretreatment to enhance the extractability of bioactive compounds from olive pomace, in order to use the obtained extracts as natural ingredients to extend shelf life of fresh-cut apples.

The olive pomace was irradiated at room temperature in a Co-60 semi-industrial facility (absorbed dose: 5 kGy; dose rate: 10 kGy/h) [1] and further extraction of phenolic compounds was carried out using a heat-assisted method previously optimized [2]. The performance of olive pomace extracts in extending shelf life of fresh-cut apples was assessed using two different packaging films (biodegradable polylactic acid - PLA, and oriented polypropylene - OPP) and compared with ascorbic acid, a commercial antioxidant used by the food industry. Physicochemical parameters (firmness, color and weight loss), atmospheric composition inside the packages, microbial load (total mesophilic bacteria, coliforms and filamentous fungi), phenolic content and antioxidant activity (FRAP assay and DPPH scavenging activity) of the fruits were assessed throughout the 12 days of storage at 4 °C.

The results demonstrated that the natural extracts from irradiated olive pomace increased the antioxidant activity of the fruits and inhibited the microbial growth better than ascorbic acid during storage with refrigeration for at least five days, preserving the color of the slices after a slight initial browning of the samples. Regarding the used packaging films, PLA films exhibited higher potential to preserve the quality of fresh-cut apples in combination with olive pomace extracts compared to conventional films, showing a lower microbial diversity of these samples. The promising results obtained in this work support the antimicrobial potential of olive pomace extracts and are in line with consumers' requirements for high-quality and safe processed foods, reducing the environmental impacts and promoting the sustainability of the olive oil industries.

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DEVELOPMENT OF AN EFFICIENT PROTOCOL FOR THE EFFECTIVE USE OF LABORATORY RESOURCES FOR THE IMPLEMENTATION OF COUNTRYWIDE CONTROL AND MONITORING OF IRRADIATED FOOD

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The national monitoring of irradiated food, conducted by the Radiation Physics Laboratory (RAD-LAB) within the governmental food safety-monitoring program, utilized a meticulously crafted protocol to boost efficiency and accuracy. This protocol ensured comprehensive sample collection, inspection, and testing methods, thereby guaranteeing reliable results while maximizing the economy of laboratory resources, conducting examinations of a large number of samples.

Samples, collected randomly from the market by authorized inspectors, were carefully handled to prevent contamination and light exposure. Upon receipt, samples were cross-checked against accompanying Sample Minutes and visually inspected for any indications of irradiation history. Two distinct groups were formed based on the presence or absence of irradiation labels upon sample admission. Group one contained samples with explicit irradiation labels, while group two lacked such labels. Both groups underwent initial examination using the Pulsed Photon-Stimulated Luminescence - PPSL method. Positive results from group one prompted immediate issuance of Test Reports, while negative or intermediate outcomes necessitated further scrutiny via the Thermoluminescence - TL method. Group two samples underwent additional TL method testing upon positive or intermediate PPSL results.

PPSL measurements were carried out using the SUERC irradiated food screening system, adhering to EU standards (EN 13751:2011). Conversely, TL method measurements utilized the Riso TL/OSL reader DA-20, following EU standards (EN 1788:2011). Test Reports included detailed sample identification, dates, testing results, and interpretations categorized as positive, negative, or undetermined regarding irradiation.

Out of 140 samples, including dried herbs, spices, vegetables, and seasonings, 25 underwent additional TL method testing. Results showed that 6.43% of samples exhibited indications of irradiation, 92.86% showed no such indications, and 0.71% were deemed indeterminate due to insufficient mineral isolation. Notably, 55.56% of irradiated samples bore the "Radura" label, while 3.85% of unlabeled samples exhibited no irradiation indications. Overall, 10% of samples were non-compliant.

The monitoring program aimed to ensure consumer rights and industry compliance but lacked data on irradiation-prohibited foods like milk and meat, indicating the need for broader methodological expansions. In conclusion, the protocol ensured efficient and accurate testing, emphasizing the program's importance in upholding food safety standards and regulatory compliance. Future efforts should address testing methodology gaps for comprehensive monitoring.

GAMMA IRRADIATION AS AN EFFICIENT TECHNIQUE FOR THE SYNTHESIS OF MAGNETIC NANOSTRUCTURES

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Magnetic iron oxide nanoparticles (NPs) and their magnetic gels are versatile materials with applications ranging from catalysis to biomedicine. However, their radiolytic synthesis has only recently gained more attention due to the complex iron oxide chemistry. The talk will provide an overview of our research on γ -irradiation synthesis of magnetic nanostructures with well-defined properties and their applications in catalysis and surface-enhanced Raman spectroscopy (SERS). Systematic studies have elucidated the influence of experimental factors such as dose, pH and crucial role of polymer type and concentration on the reducing conditions and hence formation of iron oxide NPs of controlled size, shape and phase composition [1,2,3]. Optimal conditions, particularly using DEAE-dextran as a stabilizing agent, have been identified to produce monophasic superparamagnetic spherical magnetite NPs and feroxyhyte nanodiscs efficiently. Recent efforts have focused on optimizing conditions for stable concentrated ferrofluid formation, as well as on exploring the influence of NP morphology on magnetic properties, by synthesizing magnetite NPs in the form of nanodiscs. Additionally, the reducing power of Fe^{2+} formed on irradiation was explored to synthesize composite iron oxide/gold [4] and iron oxide/silver nanostructures. Particles demonstrated high catalytic efficiency in pollutant (4-nitrophenol) reduction reactions. The highest efficiency was the result of the optimal concentration and size of noble metal NPs on the surface of feroxyhyte nanodiscs. Furthermore, these NPs exhibit promising SERS activity for detecting organic compounds in aqueous solutions. SPION/Ag NPs proved to be a better SERS substrate compared to equivalent SPION/Au NPs, which was opposite to their catalytic activity. Depending on the type of probe molecules, δ -FeOOH/Ag NPs enabled good SERS enhancement and detection of up to 10^{-9} M of 4-MBA. Recently, strontium hexaferrite NPs have been synthesized using a combination of wet chemistry, gamma irradiation and thermal treatment, offering new opportunities for magnetic material synthesis. Furthermore, magnetite nanocomposite hydrogels synthesized via one-step γ -irradiation and preliminary results on magnetic polysaccharide gels will be discussed.

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INVESTIGATION OF RHODAMINE NANO-CLAY RADIO-FLUOROGENIC GEL DOSIMETERS BY PHOTOLUMINESCENCE-DETECTED PULSE RADIOLYSIS

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The significance of real-time dose evaluation has been anticipated alongside recent advancements in radiotherapy. Nevertheless, conventional methods reliant on gel dosimeters encounter hurdles due to delayed dose responses stemming from the slow completion of radiation-induced chemical reactions which take some hours or some days to complete the reaction.

This study introduces a pioneering technique termed photoluminescence-detected pulse radiolysis (PLPR) and explores its potential for enabling real-time dose measurements through nano-clay radio-fluorogenic gel (NC-RFG) dosimeters [1,2]. PLPR is a time-resolved observation method, and enables time-resolved fluorescence measurement. NC-RFG dosimeters were prepared, typically consisting of 100 μ M dihydrorhodamine 123 (DHR123) and 2.0 wt.% nano-clay (Laponite XLG), along with catalytic and dissolving additives. We successfully achieved time-resolved observation of the increase in fluorescence intensity upon irradiation of the dosimeter, as seen in Figure 1. PLPR technique allowed for dose evaluation merely 1 second post-irradiation. The dose-rate effect was not observed for the deoxygenated conditions, but was observed for the aerated conditions. Besides the dose-rate effect, linear dose responses were obtained for both conditions up to 75 Gy. Furthermore, we made a novel observation of a decay in fluorescence intensity over time in the early stages, termed fluorescence secondary loss (FSL). The reaction mechanism of this dosimeters also discussed from the fundamentals.

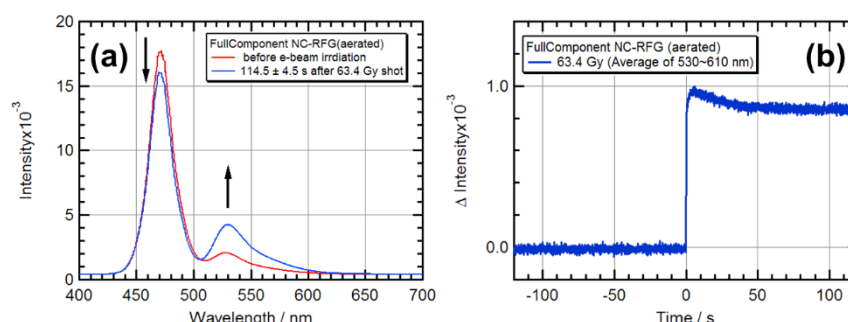


Figure 1. Example of PLPR measurement of NC-RFG. (a) spectra of before and after electron beam irradiation, and (b) time course of the fluorescence intensity.

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RADIATION STABILITY OF NANOCOMPOSITE SCINTILLATORS

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Radiation stability is a key parameter of all materials that are exposed to the field of ionizing radiation during its practical use. Moreover, the radiation stability is essential to assessment of the economy of operation scintillation detectors, where high radiation stress is expected, and to evaluate the lifetime of such components in complex and expensive devices. An inorganic, usually bulk, scintillators tend to be an advantageous for their radiation hardness, on the contrary of organic scintillators with relatively low radiation stability especially in the field of high energy radiation. Due to the advent of a new nanocomposite scintillators developed for advanced applications, such as time-of-flight PET or high energy physics, the radiation stability of these new materials composed of inorganic nanoparticles and polymer matrix becomes a serious concern.

This study is focused on the investigation of radiation stability of the nanocomposite scintillators under X-rays and electron beam irradiation. Such nanocomposites consist of scintillating nanoparticles (i. e. particles whose size does not exceed 100 nm in at least one direction) embedded into the optically appropriate matrix. Nanoparticles of ZnO:Ga or CsPbBr₃ have a tunable luminescence and sub-nanosecond photoluminescence and scintillation decay [1,2]. Especially because of their superior timing properties, they were identified as promising materials for time-of-flight applications in medical imaging and high energy physics fields [3]. Regarding matrices, polystyrene (PS) was found to be an appropriate host material with many advantages. PS itself is a good scintillator and the incorporation method we use allows for homogenous distribution of a scintillating nanopowder, which is a crucial requirement for effective nanocomposite. Moreover, the efficient non-radiative energy transfer from the host matrix towards ZnO:Ga was evidenced [2]. On the other hand, the low radiation hardness of PS can significantly limit their use in detection systems, where radiation damage of the matrix could affect the detection properties of such systems.

We focused our research on the evaluation of radiation damage of various PS nanocomposites suitable as detectors for fast timing applications, namely ZnO:Ga-PS and CsPbBr₃-PS. The effect of X-rays and electron irradiation on the absorption and luminescence properties was investigated in detail. This research has been supported by the Ministry of Education, Youth and Sports of the Czech Republic (grant number CZ.02.1.01/0.0/0.0/16_019/0000778) and OP JAC financed by ESIF and the MEYS (Project No. SENDISO - CZ.02.01.01/00/22_008/0004596).

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ASTROCHEMISTRY OF CALCIUM CARBONATE – THE ROLE OF LOW-ENERGY PROTON IMPLANTATION

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The presence of calcium carbonate is observed in many interesting regions of space within and beyond the Solar System. [1,2] Because of its industrial and scientific importance, the radiolysis of this carbonate mineral has been studied under a variety of experimental conditions. Many previous studies reported the formation of radiolysis products with potential astrochemical significance (e.g. small molecular weight carboxylic acids, oxocarbon radicals etc.) in the irradiated matrices. [3,4] Although, to our knowledge, there were no experiments conducted in model systems addressed to simulate the effects of physical-chemical environment present in space, on the chemical composition of carbonate minerals.

The AQUILA irradiation chamber, which is located at the HUN-REN Institute for Nuclear Research, makes possible the irradiation of various target materials at low temperatures, by ions of different charge states (Q) with kinetic energies ranging from $Q \cdot 500$ eV to $Q \cdot 20$ keV. In our experiments we investigated the compositional changes of calcite layers bombarded by 10 and 2 keV protons at 20 K with Fourier-transformed infrared spectroscopy and mass spectrometry techniques. These conditions are mimicking the effects of fast solar wind and stellar suprathermal protons on carbonate-bearing interplanetary dust particles.

We observed the formation and entrapment of carbon-dioxide and carbon-monoxide in the processed samples. The ratio of these two main products showed significant dependance on the projectile energy. Some characteristic changes in the infrared spectra of the irradiated samples suggest that proton radiation can induce recrystallization in calcite even at very low temperatures.

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RADIATION-SYNTHESIZED POLY(ACRYLIC ACID) NANOGELS AS RADIOISOTOPE CARRIERS FOR CANCER THERANOSTICS. FROM SYNTHESIS TO ANIMAL STUDIES

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The aim of this work [1-4] was to synthesize, using radiation technique, polymer nanocarriers for theranostic radioisotopes, test their physicochemical properties, prove their effectiveness in vitro and check how they behave in vivo, on an animal model. While radiation synthesis of internally crosslinked nanoparticles – nanogels – is known since some time, here we took a closer look at the influence of reaction conditions on the product properties using the state-of-the-art triple-detection Gel Permeation Chromatography. This allowed us to distinguish two stages of the intramolecular cross-linking mechanism and to optimize the synthesis conditions. Physicochemical studies yielded detailed characteristics of nanogels and confirmed their stability in physiologically relevant media. In the next step, nanogels have been derivatized by covalently attaching functional groups – the targeting ligand (providing selective attachment to prostate tumor cells), the radioisotope chelating moiety and, optionally, a fluorescent label. Subsequently, radiolabeling studies have been conducted using ¹⁷⁷Lu or ⁹⁰Y yielding optimized isotope-binding procedures. The so obtained nanoradiopharmaceuticals have been demonstrated to be highly selective in vitro towards prostate tumor cells. Moreover, internalization of radioactivity was substantially increased upon application of the delivery vehicle, in comparison to free radioisotopes. Less satisfactory results have been so far obtained in the animal studies (rat model), where high accumulation of nanoparticles in liver prevented effective targeting of the tumor. While bioavailability of the nanocarriers is high and no adverse radiation-induced effects in the liver were found, there is a need for optimization of the product to improve its in vivo targeting. Our results indicate a relationship between targeting efficiency and particle size, but the latter is evidently not the only factor, leaving field for further improvement of the concept and providing more efficient nanocarriers.

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MODULATING HYDROLYSIS AND ZETA POTENTIAL IN AMINE-FUNCTIONALIZED NANOGELS: SYNTHESIS, SIZE CONTROL AND PH RESPONSIVE PROPERTIES

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Poly(vinylamine) (PVAm) is a highly valuable polymer due to its excellent biocompatibility, strong cationic nature, and potential for functionalization. The primary amine groups in PVAm facilitate interaction with negatively charged biological molecules, making it ideal for biomedical applications such as drug delivery, gene therapy, and tissue engineering [1].

In this study, the synthesis and hydrolysis of Poly(N-vinylformamide) (PNVF) to PVAm was systematically investigated to understand its impact on zeta potential and hydrodynamic size. By methodically varying the hydrolysis ratio, precise modulation of the zeta potential in the resulting polymers was achieved, a critical factor influencing their stability and interaction with various biological interfaces. The degree of hydrolysis was precisely determined using Nuclear Magnetic Resonance (NMR) spectroscopy, ensuring accurate characterization of the hydrolyzed products. Dynamic Light Scattering (DLS) was employed to conduct in-depth zeta potential and size measurements across a pH range from 2 to 14, demonstrating the different pH sensitivity behaviors of the hydrolyzed products. Different solvent mixtures were studied to achieve significant control over the size of polymer coils before irradiation.

Nanogels were synthesized from both PNVF and PVAm with different hydrolysis ratios using gamma irradiation. This method facilitated the formation of novel nanogels with unique properties and allowed a thorough examination of their structural and functional characteristics. The synthesized nanogels exhibited a range of zeta potentials and sizes, meticulously controlled through the hydrolysis process. The size and zeta potential of nanogels are crucial as they directly influence cellular uptake, distribution, and stability in biological systems [2]. Thus, DLS and Atomic Force Microscopy (AFM) were used to characterize the nanogels, providing detailed insights into their pH sensitivity and morphology.

These findings contribute to the broader understanding of PVAm behavior in aqueous environments and open new avenues for the development of advanced polymeric materials with customizable properties. The methodologies and results discussed in this study offer a comprehensive framework for the development of functional nanogels with tailored properties, open for innovative solutions in biomedical applications.

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POSTERS

RADIOLYSIS OF LEAD IODIDE AND RELATED PEROVSKITE MATERIALS INDUCED BY XUV/X-RAY LASERS AND OTHER SOURCES

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Lead iodide PbI₂, a wide band gap semiconductor with a layered crystalline structure, is a material exhibiting interesting and useful behavior when exposed to either ionizing or non-ionizing radiation. Numerous related applications of lead iodide and its derivatives have been reported, including photography and radiography, detection of ionizing radiation, photovoltaics (solar cells), imprinting of laser beams and other fields of science and technology. The radiation-chemical study of lead iodide and derived materials also offers deeper insight into the general mechanisms of radiation damage in complex solids.

Perovskite materials, containing a complex lead iodide anion [PbI₃][−] and either an organic or inorganic cation, show a counterintuitive pattern in their radiolytic responses. From common experience, one may expect lower radiation resistance of organic-cation-based perovskites in a comparison to entirely inorganic materials like Cs[PbI₃]. However, some experiments gave contradictory results [1, 2]. Current explanations are based on a dynamic “self-healing” effect associated with the organic moiety in hybrid perovskite materials.

As a heavy, high-Z material, lead iodide has been proven to be very suitable to ablation imprinting of focused x-ray free-electron laser (FEL) beams, see for example [3,4], and references cited therein. From damage patterns, physicists extract information on the beam and its interaction parameters (e.g., lateral distribution of intensity, fluence, focal spot diameter, and tight focus position) [4] while chemists are interested in mechanisms of x-ray-laser induced decomposition reactions and phase transitions occurring in the irradiated material. At the extremely high dose rates typical for such sources, a key question arises whether the character of the damage process is either thermal or non-thermal. Special attention should be paid to a possible interplay of thermal and non-thermal effects. In this contribution, results obtained with focused beams of x-ray FELs and XUV capillary-discharge lasers (CDL) are presented.

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OPTICAL PROPERTIES EVALUATION OF STERILIZED PET BLOOD TEST TUBES

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Radiation Sterilization Center of Ural Federal University sterilize single used medical products. One of these products is blood test tubes manufactured from polyethylene terephthalate (PET) compound. PET is optically transparent material with band gap 3,88 eV [1] and have luminescence in visible region under excitation by different kinds of irradiation. During E-beam irradiation PET is degraded due to chemical compound transformation that is lead to luminescence properties changing. It is interesting to understand how optical properties of real PET product are changing during E-beam irradiation and how it can be used in industrial procedure of sterilization.

In this work we measured optical absorption, luminescence and excitation spectra of blood test tubes irradiated by 10 MeV E-beam with absorbed doses corresponding to sterilization and maximum acceptable values in compare with higher dose. Studying shows that luminescence of irradiated PET presents with non-elementary band in the region 2-3.5 eV with two components and transforms during irradiation with changing of peaks maximum position and redistribution of their intensity. Optical absorption spectrum is changing under E-beam irradiation, too, and gives information about decreasing of bandgap value.

All the changings of optical properties are stable in time and can be used for instance to confirm a fact of radiation sterilization procedure as independent way without absorbed dose dosimeters utilizing.

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INCREASE OF YIELDS OF HYDROXYL RADICALS DUE TO THE DECOMPOSITION OF HYDROGEN PEROXIDE BY GOLD NANOPARTICLES UNDER PROTONS AND HEAVY IONS

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It has been known that gold nanoparticles (GNPs) can enhance the biological effectiveness of radiation therapy. The enhancement of the biological effectiveness has been seen in biological experiments using small animals and living cells, but the mechanism is not fully clarified. One of the possible mechanisms is the increase of the indirect action, which is governed by hydroxyl radicals. Therefore, we, in the present study, evaluate changes in yields of hydroxyl radicals due to GNPs under protons and heavy ions.

The yield change of hydroxyl radicals is measured using Ampliflu Red solutions with 1 μ M, in which we can access primary yields. For example, under Bragg peak energy C ions, yields of resorufin, which are proportional to hydroxyl radical yields, increase by 1.5 times due to the addition of GNPs (Figure 1). This yield change is reasonable with the decomposition yields of hydrogen peroxide. In the presentation, we will present results of other ion species (e.g., protons and He ions) and yield change of hydrogen peroxide. Additionally, we will mention results under high-energy heavy ions beams.

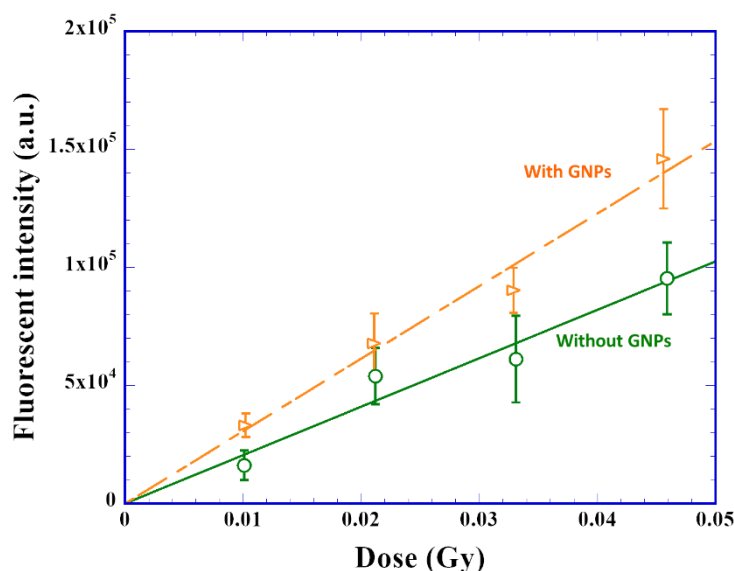


Figure 1. Evolution of fluorescence intensity of under the effect of C ions.

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GAMMA-RAY ASSISTED REDUCTION OF GRAPHENE OXIDE THIN FILMS: PRELIMINARY RESULTS

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One of the main approaches for the mass production of graphene-based materials involves the oxidation of graphite to graphene oxide (GO), followed by chemical reduction to produce reduced graphene oxide (RGO). The radiolytic synthesis of RGO presents several advantages such as the absence of toxic chemicals and high purity of product, as demonstrated by γ -ray irradiation of GO in IPA:H₂O suspensions [1] and in gaseous phase under analytical grade air, N₂ or H₂ [2].

Here we present a pathway to produce RGO coatings on substrates with increasing morphological and structural complexity, from surfaces with controlled roughness to mesoporous sponges. Taking advantage of the high processability of GO in aqueous solutions to create uniform coatings with controlled thicknesses of a few nanometers and a subsequent gamma-assisted reduction, without modifying the chemical-physical properties of the substrate. The samples are immersed in a solution of IPA:H₂O (1:1) and then irradiated with a ⁶⁰Co source using a Gammacell 220 Nordion at absorbed dose of 44 kGy.

Preliminary measurements are performed on suspension of single GO nanosheets. Then we produced GO thin films on silicon substrate and Kapton. As confirmed by X-ray photoemission

spectroscopy, the C/O ratio of γ -ray reduced graphene oxide is increasing from 3.0±0.1 GO to 8.3±0.7 upon irradiation. Raman measurements are in agreement with such results. Finally, we irradiated GO-coated commercial polyethersulfone (PES) hollow fibres successfully used for water treatment. It was previously demonstrated that RGO increases the retention efficiency of poly-fluoroalkyl substances (PFAS) contaminant 3-5 times higher than the commercial granular activated carbon [3]

Preliminary tests confirm that γ -ray exposure does not affect the polymeric matrix or their filtering performance. Currently, γ -ray irradiation on GO coated PES fibers are in progress.

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INFLUENCE OF IONIZING RADIATION ON POLY(N-VINYL-2-PYRROLIDONE) IRRADIATED IN SOLID STATE AND AQUEOUS SOLUTIONS

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Radiation is an effective and established tool to sterilize medical and healthcare products including a wide range of single-use medical products and devices. Sterilization is mostly done using gamma sources, however a transition to accelerator-based sterilization is being observed. Lack of the knowledge of radiation effects on polymers for electron beam is one of the reasons to impede the spreading use of these technologies.

Increasing need of the knowledge of sterilization or re-sterilization of medical devices is the other reason to continue a detailed research study on influence of ionizing radiation on polymer-based products used in medicine.

The purpose of this work is to expand our understanding of radiation effects on selected polymers and polymeric materials commonly used in medical devices by comparing gamma and electron beam irradiation. The first analyzed polymer was poly(N-vinyl-2-pyrrolidone) (PVP). Basic physico-chemical properties of unirradiated material have been examined with the use of static- and dynamic light scattering as well with gel permeation chromatography (triple detection: multiangle light scattering, refractive index and viscosity have been used to obtain absolute values). The next stage of studies was devoted to comparison of effect of irradiation on poly(N-vinyl-2-pyrrolidone) with three different dose rates (gamma and electron beam irradiation), both in a solid state and in aqueous solution. In case of irradiation in the solution saturation with inert gas (argon) has been also analyzed.

Acknowledgement

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UTILIZING GAMMA IRRADIATION WITH GREEN ANTIBACTERIAL AGENTS AS A PROMISING ALTERNATIVE FOR PRESERVING HISTORICAL TEXTILES

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An important part of the cultural artifacts in Türkiye is composed of textile materials, such as national costumes, uniforms, flags, carpets, and many other items. Textiles have been recognized as a medium for the proliferation of microorganisms, including bacteria and fungi. The growth of these microorganisms on textiles causes adverse effects on the textile materials. Due to the biocide effect of ionizing radiation, this technique can be used for the disinfestation of textile artifacts. As is well known, identification of the D₁₀ value allows the choice of the minimum radiation dose that guarantees sufficient microbicidal effect. However, the high D₁₀ value can cause changes in the molecule structure of organic fibers and natural dyes used in historical textiles. In this study, the effect of the combined application of some green synthetic antibacterial agents with ionizing radiation on the reduction of the dose required for disinfestation of cultural heritage textiles has been investigated. Bacterial contamination level was determined using the sterilized cotton swaps method from the historical textiles stored in the Ethnography museum. The samples were inoculated on yeast extract glucose chloramphenicol agar to obtain bacterial colonies and were then incubated at 28 °C for 72 h. Each sample was irradiated by a cobalt-60 irradiator (Ob-Servo Sanguis) at doses of 0, 1, 3, and 5 kGy and the D₁₀ value was determined from the slope of survivors versus the dose plot. The D₁₀ value was calculated as 1.19 ± 0.02 kGy. Accordingly, a dose of 7.60 kGy is required to reduce the bacterial population down to the blank sample level. This dose value can induce alterations in the molecular composition of organic fibers and dyes. Therefore, gamma irradiation at doses that do not affect the quality of textile materials followed by the application of antibacterial agents can provide the desired antimicrobial effectiveness. For this purpose, three Schiff bases (L1, L2, L3, and L4) were synthesized and used as green antibacterial agents against the gamma-ray-resistant bacterial colony. Antibacterial activities of the Schiff bases were evaluated by measuring inhibition zone diameters and found to be 9.21 mm for L1, 8.10 mm for L2, 10.13 mm for L3, and 10.48 mm for L4. Molecular docking studies were conducted using AutoDock v. 4.2.6 software to investigate the variance in antibacterial activity among the Schiff bases.

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THE INFLUENCE OF DIFFERENT RADIATION MODALITIES ON POST-IRRADIATION BEHAVIOUR AND PROPERTIES OF HIGHLY CRYSTALLINE PP

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Ionizing radiation and ethylene oxide (EtO) gas are the two most widely used methods of sterilization of single use (SU) medical devices. Concerns regarding EtO health, security and environmental threats are driving SU medical device manufacturers toward radiation technologies. Furthermore, radiation modalities from machine sources such as X-ray and electron-beam (E-beam) offer potentially beneficial alternatives to the most widely used sterilization by gamma rays, which is limited by availability and tightness in the supply of Cobalt-60. Furthermore, it is well known that ionizing radiation can significantly alter the structure and properties of polymers as primary constituents of SU medical devices. Polypropylene (PP), a widely used material in the medical industry, belongs to polymers sensitive to ionizing radiation even for relatively small doses (in the range of sterilization ones) and undergoes excessive oxidative degradation and deterioration in properties upon irradiation in the air [1,2]. Therefore, the influence of different processing conditions and irradiation modalities must be thoroughly investigated for this material.

Herein, PP homo-polymer samples with a high level of isotacticity were prepared by slow cooling after compression molding in order to obtain a structure with the highest possible degree of crystallinity. Thereafter, samples were irradiated by electron-beam and gamma radiation. The presence and evolution of free radicals were followed using electron spin resonance (ESR) spectroscopy up to 6 months. Additional characterization was conducted by scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), wide angle X-ray diffraction (WAXD), dielectric relaxation spectroscopy (DRS) and mechanical measurements. The results are analyzed, compared and discussed, emphasizing doses used to sterilize medical devices.

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PROTON BEAM DEGRADATION OF IBUPROFEN IN-AIRE. Furu¹, R. Huszánk¹¹ HUN-REN Institute for Nuclear Research (ATOMKI), Debrecen, Hungary

2-[3-(2-methylpropyl) phenyl] propanoic acid, commercially available as ibuprofen (IBP), is widely used as Non-steroidal Anti-Inflammatory Drug (NSAID, generally prescribed for the treatment of fever, muscle aches, arthritis and tooth aches [1]).

Some reports have confirmed the presence of the IBP and its metabolites, in effluents of wastewater treatment plants (WWTPs) [2]. Although, the concentration of IBP is very low in aquatic systems, and they may present a potential hazard for human health. Besides its metabolites may be more harmful than the parent organic compounds [3].

IBP is not easily degraded under the typical biological treatments in the municipal wastewater treatment plants. Therefore, several enhanced technologies, which can reduce the IBP presence in the environment, have been suggested. They are called advanced oxidation processes (photodegradation, electron and gamma irradiation, [4,5,6]) and biological treatments [7].

This presentation aims to introduce results obtained on the degradation of IBP by proton irradiation with an in-air ion beam irradiation setup, operated by 2 MeV protons. In the ATOMKI the Tandetron accelerator was used to produce the proton beam. The degradation of IBP followed by UV/VIS spectrophotometry. Preliminary results showed that IBP concentration decreased with an increasing absorbed dose. When IBP concentration of 12 mg/L and an absorbed dose of 30 kGy were chosen, IBP degradation percentage was about 40%.

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GAMMA FACILITY, IRRADIATION APPLICATIONS IN AZERBAIJAN

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Gamma irradiation technology is a key tool in the field of radiation processing, offering flexible solutions for various sectors such as medical sterilization, food safety, polymer modification, and agriculture. Establishing a gamma irradiation facility in Azerbaijan is a significant technological advancement. Present work provides an overview of gamma irradiation in Azerbaijan, highlighting its applications, technical specifications and operational framework of the gamma irradiator facility, showing its capabilities as a platform for innovation in various industries.

The work evaluates the role of gamma sterilization of healthcare products, which is essential for maintaining hygiene in healthcare facilities. It also helps to control microbial contamination and extend the shelf life of perishable goods, ensuring food safety. In addition, the work explores gamma irradiation's applications in agriculture, such as seed sterilization, pest management, and crop improvement, which support sustainable agricultural practices and increase yields.

This work illuminates highlights Azerbaijan's research and prospects in leveraging gamma irradiation technology for societal benefit and sustainable development. It demonstrates the country's commitment to embracing advanced technologies and fostering innovation across various domains.

CELL VIABILITY AND METABOLIC CHANGES IN *STAPHYLOCOCCUS AUREUS* FOLLOWING GAMMA IRRADIATION UNDER DIFFERENT CONDITIONS

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The main goal of this study was to analyze the effect of ionized radiation on bacterial cells viability and metabolic activity of *Staphylococcus aureus*. In this purpose we have optimized a working protocol and we have evaluated the compatibility of analytical methods with the expected changes after treatment.

The evaluation of microbial viability and response to treatments is usually based on multiplication capacity. However, preparing microbial suspensions and counting colonies is time consuming and labor intensive. In addition, cellular response to treatments is not always limited to the inability to reproduce, and the incapacity to do so does not always imply that a cell has lost viability.

Colorimetric procedures are economical, fast, can measure multiple samples simultaneously, can be automated, and are preferred for assessing the physiological state of microorganisms [1,2].

Aliquots of *S. aureus* (ATCC 6538) suspensions of 5×10^7 CFU / ml were subjected to γ -irradiation treatment at three doses (200, 400 & 800 Gy) and two dose rates (D_1 - 0.47 Gy/s & D_2 - 0.12 Gy/s). The irradiation treatment was performed in IRASM Department, using a Gamma Cell irradiator GC-5000.

S. aureus cell viability and metabolic activity was simultaneously measured by plate spectrometry. Viability was confirmed by cultivation method (colony counting). For establishing a more comprehensive protocol, we tested several chromophores (Resazurin, MTT, Live/ Dead kit) and time intervals after treatments.

Based on the color change of positive wells, correlated with dilution factor and irradiation dose, we calculated the D_{10} values. The obtained value was similar to the one from cultivation method.

In the same time, in contrast with traditional way of establishing D_{10} , by reading in kinetic mode, an extensive amount of information regarding the metabolic activity was gathered and used for comparisons.

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CHANGES IN ANTIBIOTIC SUSCEPTIBILITY OF *STAPHYLOCOSSUS AUREUS* STRAINS DUE TO GAMMA IRRADIATION AND DIFFERENT SALT CONCENTRATIONS

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Staphylococcus aureus is a significant pathogenic bacterium in food safety concern. Although it is a Gram-positive bacterium that is easily destroyed by heat treatments such as cooking or pasteurization, it can secrete heat-stable toxins if food is cross-contaminated. In 2019, the World Health Organization (WHO) identified antimicrobial resistance (AMR) as one of the top 10 global public health threats, with methicillin-resistant *S. aureus* (MRSA) being a major causative agent of bloodstream infections. In 2020, there were 43 reported outbreaks of *S. aureus* toxins in the EU, affecting 402 individuals. *S. aureus* demonstrates extensive adaptability, including resistance to antibiotics through the acquisition of resistance genes and the ability to withstand stress factors like high salinity.

Gamma irradiation is an effective method to ensure food safety with minimal impact on food quality. In light of growing antibiotic resistance, this study aimed to examine the response of an MRSA and a sensitive *S. aureus* to antibiotics following exposure to environmental stressors. High salinity (osmolarity) and sublethal doses of gamma irradiation were used as stress factors. The study assessed changes in antibiotic susceptibility and resistance before and after stress application, along with genotypic analysis to detect the *mecA* gene, which is responsible for beta-lactam antibiotic resistance.

Two *S. aureus* strains, an MRSA and an MSSA, were tested for antibiotic susceptibility using the agar disk diffusion method with ten antibiotics. The MRSA was further subjected to 6% NaCl concentration and 0.6 kGy of gamma irradiation, individually and in combination. Comparisons were made with a control sample that was neither salted nor irradiated. Changes in bacterial survival and antibiotic resistance were measured, and a PCR test was performed to detect the *mecA* gene in both intra- and extracellular DNA.

As a result it was observed that stress factors altered behaviour towards antibiotics, with some antibiotics showing increased susceptibility and others increased resistance. Notably, meropenem resistance decreased to an intermediate level with increasing NaCl concentrations (6%, 10%, 12%), and susceptibility was restored after gamma irradiation alone or combined with high salinity. PCR results confirmed the presence of the *mecA* gene across all treatments, indicating no genetic change. The bacterial count decreased significantly, particularly with irradiation.

In conclusion, high salinity and low dose of gamma irradiation decreased resistance to meropenem in MRSA. The *mecA* gene remained present, suggesting resistance loss might be due to inhibited gene expression or altered membrane permeability. These findings indicate that the combined stressors could enhance the uptake of antibiotics, potentially offering a strategy to combat antibiotic-resistant *S. aureus*.

IONIZING RADIATION EFFECTS ON OPPORTUNISTIC PATHOGENIC BACTERIAL STRAINS IN THE PRESENCE OF PIPERACILLIN

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Antibiotic-resistant bacteria are increasingly posing significant challenges in both human and veterinary medicine, as well as in food processing. The misuse of antimicrobial agents has led to the emergence of multidrug-resistant pathogens. In livestock production, antibiotics are utilized as feed additives to reduce slaughter losses. Currently, antibiotic resistance represents a global public health risk that affects both the present and future generations.

We investigated the effects of gamma irradiation at varying doses (0.2, 0.4, 0.6 kGy) on the growth kinetics of piperacillin-resistant and sensitive strains of *Escherichia coli* C3, B.01748, *Staphylococcus aureus* B.02174, and B.01755 in distilled water containing trace amounts of piperacillin (2.5 ng/L). The research aimed to understand the impact of irradiation and the presence of antibiotics on the population dynamics of these opportunistic pathogenic bacterial strains. Following irradiation, microbial proliferation in a liquid medium (Don Whitley) was monitored for 24 hours. The real-time growth of the initial cell concentration, which was 106 cells/ml, was tracked using both the Rapid Automated Bacterial Impedance Technique (RABIT) for measurements of medium impedance ($\mu\text{S h}^{-1}$) and the Multiscan Ascent instrument for measuring the optical density of growth curves. Each treatment was performed in 3 parallel replications. After inoculation into the medium, the quantity of microbes does not change immediately. Initially, the cells adapt to the new environment (lag phase) [1]. The lag phase of the examined bacterial strains increased proportionally with the absorbed dose. By the end of the observation period, the curves for all microbial measurements reached plateau, indicating that population growth had ceased. For the *Escherichia coli* strains, we did not find significant differences in the rate of population growth. For both strains, it can be stated that irradiation in the presence of a trace amount of piperacillin did not result in significant changes in the survival of the irradiated cells, nor in the subsequent development of cell numbers. The proliferation kinetics of the two strains were determined by the absorbed dose. In contrast, for the *Staphylococcus* strains, 0.6 kGy dose resulted in a significantly lower final cell count when irradiation occurred in the presence of piperacillin. According to our results, the comparison of the two strains yielded results contrary to expectations. *Staphylococcus aureus* is generally less sensitive to piperacillin and ionizing radiation than *Escherichia coli*. However, *Staphylococcus aureus* showed greater sensitivity to sublethal combined treatments. The additive effect of these combined treatments is known as the inhibition theory, and it appears that the measured *Staphylococcus* strains were more susceptible these combined treatments than the *Escherichia* strains

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APPLICATION OF GAMMA RADIATION IN ORDER TO PREVENT THE SPREAD OF ANTIBIOTIC RESISTANCE IN *STAPHYLOCOCCUS AUREUS*

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Staphylococcus aureus (*S. aureus*) is a Gram-positive pathogen involved in a wide range of hospital-acquired and foodborne infections. The methicillin resistant variant of this bacterium plays a role in the spread of bacterial resistance. The β -lactam antibiotic oxacillin is widely used clinically to treat infections caused by *S. aureus*.

In this work we selected oxacillin sensitive and resistant *S. aureus* strains and investigated the effect of oxidative stress (high-energy irradiation) combined with the storage temperature on the survival of these strains. The effect of irradiation on cell membrane and DNA were followed and the purpose was to find out if the *mecA* gene of oxacillin, responsible for the resistance, was also modified in DNA damage.

The following characteristics were determined and analyzed: total cell numbers by microscopic investigation, culturable cell numbers by spread plate method, protein and DNA detection by fluorescent staining (FITC) and light microscopy, cell morphology by scanning electron microscopy (SEM), and the amount of the resistant *mecA* gene by PCR. Concentration values of the oxacillin and *S. aureus* used for the experiments were based on the usual concentrations in the wastewater. Samples containing 10^9 CFU cm⁻³ *S. aureus* and 0.01 g dm⁻³ oxacillin were irradiated with 0.6 kGy dose. As a result of irradiation, DNA was released from the bacterial cells and ghost cells were formed. We obtained the same result without irradiation after 7 days of storage at 25 °C due to aging. Investigating cell morphology by SEM revealed that only some of the cells had the characteristic deformation (dent, pores) typical to ghost cells. These changes are probably due to natural aging processes.

Irradiation of 10 μ g dm⁻³ DNA showed significant degradation of the target gene (*mecA* gene) at 1-2 kGy absorbed dose, (86% of the *mecA* gene was degraded at 2 kGy). Based on our experiments it seems that both the cell membrane and DNA suffer considerable damages during irradiation. Due to membrane damage, the nucleic acid in cells cannot be stained, and the DNA content of the cells slowly, in several days' period, is released into the solution. The damage of DNA includes the damage of the *mecA* gene, this gene plays key role in the development of oxacillin resistance. When wastewater is irradiated with 1–2 kGy dose, development of antibiotic resistant bacteria, due to the lack of selective pressure, is highly improbable.

GAMMA RADIATION-INDUCED SYNTHESIS OF PVP-STABILIZED PALLADIUM NANOPARTICLES ON CELLULOSE FOR PHOTOCATALYTIC DEGRADATION OF CIPROFLOXACIN

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The increasing demand for sustainable and effective materials has spotlighted cellulose, the most abundant biopolymer, for its diverse applications across industries. Recent progress has been made in enhancing cellulose by creating functional materials, with the radiation-induced grafting technique emerging as a particularly effective and environmentally friendly method [1]. Palladium nanoparticles (Pd NPs), which exhibit high catalytic efficiency in organic reactions, can be effectively stabilized by poly(N-vinyl-2-pyrrolidone) (PVP) outperforming other commonly used stabilizers like poly(acrylic acid) and poly(N-vinylimidazole) [2]. In this study, PVP-grafted cellulose (PVP@Cellulose) was synthesized using the radiation-induced grafting technique. Following this, gamma-induced reduction was carried out under eco-friendly conditions to synthesize Pd nanoparticles in the presence of the PVP@Cellulose stabilizer. The resultant nanoparticles were thoroughly characterized using SEM and XPS measurements. The cellulosic hybrid material containing Pd nanoparticles (PVP-Pd NPs@Cellulose) underwent comprehensive characterization through FTIR, XPS, and SEM analyses. This hybrid material was employed in the photocatalytic degradation of Ciprofloxacin (CIP), demonstrating significant potential for environmental remediation under UV-light irradiation. Photocatalytic tests revealed that PVP-Pd NPs@Cellulose composites with higher grafting degrees (DG) exhibited markedly superior performance, achieving up to 91% degradation of CIP within 120 minutes. The degradation process followed pseudo-first-order kinetics, with rate constants proportionally increasing with higher DG values. Samples were further subjected to six consecutive cycles of CIP degradation to assess their long-term stability and reusability. The findings highlight their effectiveness, stability, and reusability, making them a promising solution for mitigating pharmaceutical pollution in water systems.

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HYDROGEN PRODUCTION FROM RADIOLYSIS OF WATER-CONTAINING URANIUM OXIDE POWDERS

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Hydrogen is almost inevitably generated from wet radioactive wastes due to water radiolysis. The concentration of gaseous H₂ should carefully be controlled below the explosion limit, 4%. However, the amount of H₂ produced from a solid material containing water may be largely different from that expected from the water content and the radiation-chemical yield of H₂ ($G(\text{H}_2)$) of water radiolysis [1]. One example of the solid materials that affects the H₂ production is UO₂ [2], which is of particular importance as nuclear material. It is also well-known that water radiolysis oxidizes the surface of UO₂ [3]. Thus, we investigated H₂ production by irradiation of water-containing uranium oxide/hydroxide powders that have different oxidation states: UO₂, U₃O₈ and UO₂(OH)₂. The samples were synthesized from pure uranium metal (JAERI-U4) and the synthesized powders were characterized and confirmed by XRD, Raman spectroscopy, and SEM-EDX. The uranium samples were irradiated under dry condition or after addition of 5 wt.% pure water in a sealed glass tube under Ar atmosphere. The irradiation was carried out by an X-ray irradiator (acrobio AB-320). After the irradiation, the gas in the tube was analyzed by gas-chromatography. The absorbed dose was measured by the Fricke dosimeter. Based on the results, $G(\text{H}_2)$ values relative to that of UO₂ at 5 wt.% water content were calculated and listed in Table 1. When the H₂ yields were compared under the dry condition, that for UO₂(OH)₂ was higher than the other oxide samples. This result is reasonable since only UO₂(OH)₂ contains OH group which can produce H₂. Meanwhile, under the wet condition (water content 5 wt. %), the H₂ yield for UO₂ was the highest and it becomes lower in the order of UO₂ > U₃O₈ > UO₂(OH)₂. This result indicates that the oxidation state of uranium has a correlation with the H₂ yield. The relative $G(\text{H}_2)$ values were shown because the absolute values obtained by our X-ray irradiation experiments were significantly high, ex. $(1.5 \pm 0.2) \times 10^{-7}$ mol/J for UO₂ at 5 wt.% water content. It suggests that energy absorption by uranium samples for the X-ray irradiation may be much higher than that measured by the Fricke dosimeter, and further consideration about the absorbed dose is required.

Table 1. Relative H₂ yields from the uranium oxide/hydroxide samples.

Sample	UO ₂	U ₃ O ₈	UO ₂ (OH) ₂
Dry condition	0.04 ± 0.02	0.013 ± 0.005	0.09 ± 0.05
5 wt.%	1 ± 0.1	0.77 ± 0.08	0.35 ± 0.08

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THE INFLUENCE OF ORIENTATION ON THE FREE-RADICAL EVOLUTION IN DIFFERENT POLYETHYLENES EXPOSED TO GAMMA RADIATION

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This study reveals the influence of the uniaxial orientation and fibrillar structure on the free-radical evolution in different polyethylenes (PEs). For that reason, low density polyethylene (LDPE), linear low density polyethylene (LLDPE) and high density polyethylene (HDPE) samples were oriented via solid-state stretching at an elevated temperature to draw ratios sufficient to obtain the fully developed fibrillar structure. Subsequently, thus oriented samples were gamma irradiated in the air to a total absorbed dose of 300 kGy. The existence and evolution of free radicals induced by irradiation were followed using electron spin resonance (ESR) spectroscopy for three months. Furthermore, the orientation- and radiation-induced changes in morphology, crystallinity, oxidative degradation and degree of network formation were analyzed using optical (OM) and scanning electron microscopy (SEM), differential scanning calorimetry (DSC), IR spectroscopy and gel measurements. The presented results show that orientation-induced structural modifications, along with the initial differences in analyzed PE structures significantly affect the post-irradiation evolution of free radicals during storage time. Understanding of these effects is essential for the effective employment of gamma radiation to obtain improved characteristics of oriented PEs, leading to far-reaching practical applications [1-3].

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ANTIMICROBIAL DELIVERY SYSTEMS CONTAINING MESOPOROUS SILICA AND SILVER NANOPARTICLES OBTAINED THROUGH GAMMA IRRADIATION

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Antimicrobial resistance has emerged as a major concern worldwide. The extensive use of antibiotics leads to the evolution of drug resistance in pathogenic bacteria. Synergistic action of antibiotics combined with silver nanoparticles, using mesoporous silica nanoparticles as nanocarrier, presents a potential solution for this problem and offers several advantages, including reduced side effects, maximized drug efficacy, decreased dosages and targeted delivery to specific sites of bacterial infection. Furthermore, the controlled release of antibiotics at the infection site can maintain effective concentrations over prolonged periods, preventing the infection to expand.

Mesoporous silica nanoparticles have emerged as promising candidates for drug delivery systems due to their physicochemical and biological properties: high surface areas and pore volumes, adjustable pore sizes, low toxicity and high biocompatibility.

In this experiment, different types of cubic mesoporous silica with different pore sizes and volumes were synthesized by sol-gel method. The materials were impregnated with AgNO₃, using different solvents. Silver nanoparticles were obtained after Gamma irradiation at different doses ranging from 1 to 100 kGy. Hereafter, impregnation with broad-spectrum antibiotics was carried out. The purpose of this work was to obtain systems consisting of mesoporous silica, Ag⁰ and antibiotics, in order to evaluate their antimicrobial activity.

Composition of the samples was determined by thermogravimetric analysis and FT-IR spectroscopy. Textural parameters were determined by N₂ adsorption/ desorption analysis, while the crystallinity of the samples was assessed by X-Ray Diffraction. Characterization of the materials through physicochemical testing ensures their suitability for antimicrobial activity evaluation.

The antimicrobial activity of Ag⁰-MSNs, Ag⁰-drug-MSNs and free drug against *E. coli* ATCC 8739, *S. aureus* ATCC 6538 and *P. aeruginosa* ATCC 9027 was determined by well agar diffusion and broth microdilution method. Bacterial growth inhibition was evaluated by measuring optical density at 600 nm.

This study aims to optimize the synthesis process and identify potential biomedical and biotechnological applications of the developed nanoplatforms and contributes to the advancement of antibacterial therapies.

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DENATURATION OF FISH COLLAGEN EXPOSED TO IONIZING RADIATION USED STERILIZATION

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Collagen of fish origin (silver carp, *Hypophthalmichthys molitrix*, Sancoll, Poland) as a potential bioactive material of absorbable wound dressing was irradiated to determine the changes, particularly denaturation, occurring therein under the influence of ionizing radiation used as a method of sterilization of biomaterials. The advantages of ionizing radiation used to sterilize medical devices are mainly the chemical purity of the process, i.e. not using toxic chemicals, e.g. ethylene oxide, and that the sterilization is carried out at ambient temperature. Tropocollagen in the form of hydrogel (approx. 1.7% of dry weight) and freeze-dried ‘sponge’ was irradiated with an accelerated electron beam (EB) and gamma rays (γ) and then analyzed using primarily differential scanning calorimetry (DSC).

Irradiation of tropocollagen in the hydrated form (hydrogel) causes complete denaturation of the protein, i.e. disintegration of the triple helix, already at a dose of 15 kGy of EB radiation, for gamma radiation this dose is even lower (10 kGy). In the case of irradiation of a dry sponge, the damage to the triple helix is much smaller at a comparable EB dose used, and at the highest dose analyzed (100 kGy) the tropocollagen structure is still partially maintained. Influence of γ -rays on dry collagen causes greater changes in the helix, but they are not significant enough to reject the use of γ radiation as a method of sterilizing dry collagen material.

Research has shown that sterilization with an accelerated electron beam and gamma-rays of anhydrous tropocollagen obtained from freshwater fish, which is less resistant to environmental conditions and to radiation than mammalian collagen, does not denature this protein, but destroys entirely collagen triple helix when processed in hydrated state.

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RADIOLYTIC PRODUCT DISTRIBUTION IN SELF-IRRADIATED AND GAMMA IRRADIATION SOLID STATE $\text{Ca}^{14}\text{CO}_3$: NEW DATA

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Both auto-radiolysis and gamma irradiation induce transformations in solid $\text{Ca}^{14}\text{CO}_3$. Liquid chromatography followed by liquid scintillation counting were used to identify eight compounds after aqueous dissolution of the irradiated samples. The distributions of the radiolytic products depend on the gamma dose or the auto-radiolysis time. Formic and oxalic acids are the principal products, both originating from the CO_2^- ion radical. Secondary reactions produce other compounds such as glycolic, glyoxylic, acetic, and malonic acids, formaldehyde, and methanol.

The distribution of formic and oxalic acids at a dose of 0.13 MGy from self-radiolyzed solid $\text{Ca}^{14}\text{CO}_3$ was found to be 87.7% and 6.6, and there was a considerable change at a dose of 62.3 MGy of 28.8% and 56.9% respectively. When the quantity of the CO_2^- ion-radical, and the other radicals formed in the solid, increases, the possibility of combinations of these species produce changes in the percentage of the radiolytic compounds. At absorbed doses in the range of 10 to 140 kGy from gamma radiolysis, no considerable change was observed.

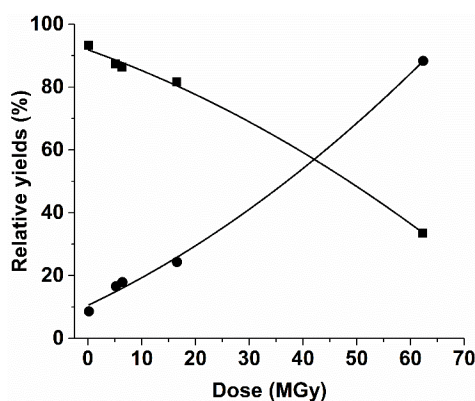


Figure 1. Relative yields of formic acid (■) and oxalic acid (●) found after dissolution of self-irradiated $\text{Ca}^{14}\text{CO}_3$, as a function of the accumulated radiation dose. (The first point is 0.13 MGy)

THE FUTURE OF γ -RADIATION MODELED AOP (ADVANCED OXIDATION PROCESSES) IN WASTEWATER TREATMENT

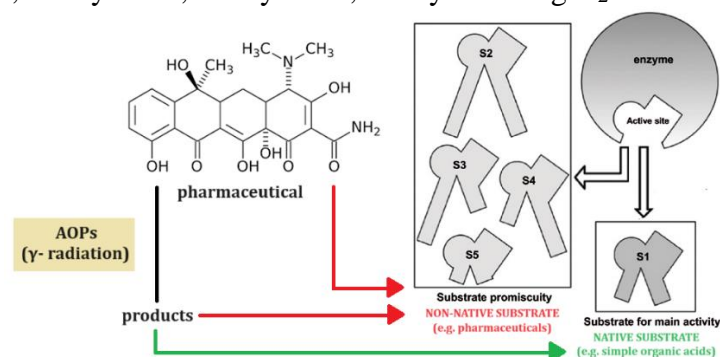
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The European Parliament has adopted revisions to the Urban Waste Water Treatment Directive (91/271/EEC) in 2024, according to which it is mandatory to operate quaternary treatment for the removal of organic micropollutants (e.g. pharmaceuticals) at many wastewater treatment plants. Among the technologies that can currently be implemented on an industrial scale, advanced oxidation processes (AOP) acting through radical generation (mainly $\cdot\text{OH}$) processes are of outstanding importance. Under experimental conditions, we model AOP with γ -radiation. Their biggest advantage is that they induce structural changes in the molecules so can help their biological degradation. Since wastewater treatment is predominantly biological treatment, this is an important feature.

In this research, we focused on pharmaceuticals and modeled AOP with γ -radiation (0; 0.5; 1; 2; 4 kGy), which we supplemented with biodegradability tests: biochemical oxygen demand (BOD) and change in biomass respiration intensity (oxygen uptake rate, OUR). AOP support the biodegradation of micropollutants in two ways. On the one hand, the structure of pharmaceuticals is simplified to a dose-dependent extent, making them easier for microorganisms to biodegrade (increasing OUR values of chlortetracycline 0 kGy: -0.13; 0.5 kGy: 0.12; 1 kGy: 0.11; 2 kGy: 0.28; 4 kGy: 0.36 mg O₂ dm⁻³ h⁻¹). On the other hand, the simple organic products formed (e.g. organic acids) stimulate the enzymes performing the biotransformation (cometabolism). The driving forces of metabolic processes are enzymes, which help the transformation of molecules (substrate). The active site is used to bind substrates, to which, in the case of certain enzymes, several molecules can bind (promiscuity). Even artificial molecules such as pharmaceuticals. The molecular structure, which is simplified by γ -radiation, also increases the chance of binding. In addition to the phenomenon of cometabolism, the OUR values increase to a much greater extent (for chlortetracycline 0 kGy: 0.48; 0.5 kGy: 1.12; 1 kGy: 1.09; 2 kGy: 0.35; 4 kGy: 0.49 mg O₂ dm⁻³ hour⁻¹).



A SPECTRAL AND KINETIC STUDY ON DEGRADATION OF METOPROLOL USING HIGH ENERGY IONIZING RADIATION

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Metoprolol tartrate belonging to the β -blockers used for treatment of cardiovascular diseases can be detected also in natural waters, wastewaters and purified wastewaters [1-3]. In this study degradation of metoprolol tartrate was investigated by Co^{60} - γ irradiation and pulse radiolysis. In $\cdot\text{OH}$ reaction the vulnerable sites of this molecule are the aromatic ring and the oxypropanolamine sidechain: $\sim 80\%$ $\cdot\text{OH}$ may attack the aromatic ring. The reaction between $\cdot\text{OH}$ and metoprolol tartrate proceeds with a rate constant of $4.8 \pm 0.3 \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ via formation of hydroxycyclohexadienyl, α -aminoalkyl and N centred radicals. Sum parameters used in wastewater analysis like chemical oxygen demand (COD), total organic carbon content (TOC) and biochemical oxygen demand (BOD) were employed to obtain information on removal efficiency in different matrices (Fig. 1). Metoprolol tartrate in 0.1 mmol dm^{-3} concentration was non-biodegradable. Based on COD and TOC results oxidation and mineralization were parallel processes. In pure water the rates of oxidation and mineralization were $16.0 \text{ mg O}_2 \text{ dm}^{-3} \text{ kGy}^{-1}$ and $1.8 \text{ mg C dm}^{-3} \text{ kGy}^{-1}$, respectively. At 5 kGy the degradation products became biodegradable in pure water. Although, the rates of the oxidation and mineralization in synthetic wastewater were smaller, the biodegradability greatly improved during the treatment. Removal of metoprolol tartrate from waters using ionizing radiation is a promising technique which can be applied in wastewater treatment plants as a fourth stage of purification.

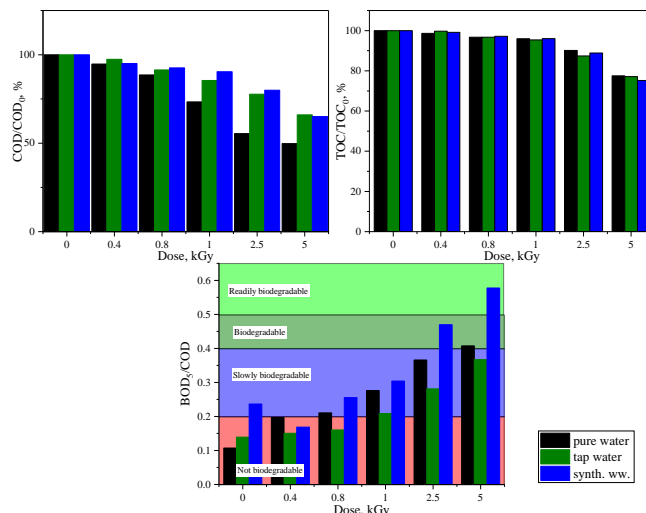


Figure 3. The change of sum parameters used in wastewater analysis in pure water, tap water and synthetic water

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PERFORMANCE AND DEGRADATION PATHWAYS OF QUIZALOFOP ETHYL AN EMERGING POLLUTANT BY IONIZING RADIATION IN AQUEOUS SOLUTION

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An efficient gamma radiolytic decomposition of one of the extensively used herbicides in the world quizalofop-p-ethyl (QPE) was explored under different experimental conditions. Aqueous solutions of QPE were irradiated by gamma rays emitted by a Cobalt 60 source. QPE aqueous solutions were irradiated at doses of 0.5–3 kGy with 26.31 Gy min⁻¹ dose rate. Obtained results indicated that removal efficiency of 98.5% and 73% of QPE were obtained, respectively, in absence and in presence of dissolved oxygen. Change of absorption spectra, pH effect and Total Organic Carbon (TOC) were carried out and studied. It was found that all absorption bands decreased with increasing absorbed dose and disappear totally after 3 kGy dose. Three pH conditions (pH = 10, pH = 6.2 and pH = 3) were applied in radiolytic degradation of QPE showing that the best removal efficiency has been found for neutral pH. Interestingly, the % TOC removal reaches 98% at 3 kGy indicated practically total mineralization. Furthermore, spectrophotometric analyses argued in favour of a pseudo-first-order kinetic of QPE degradation. The resulting apparent rate constant value is approximately $k_{app} = (0.012 \pm 0.001) \text{ min}^{-1}$. Finally, several by-products such as 6-chloroquinoxalin -2-ol, 2-(4-hydroxyphenoxy) propionate, 1,4-hydroquinone, quinone, 4-chlorobenzene-1,2-diol and 1,2,4- benzenetriol were identified by gas chromatography–mass spectrometry (GC/MS) evidencing that radiation process starting with the fragmentation of the molecule involving the hydroxyl radical, generated by the radiolysis of water. Based on the identification intermediates, a degradation mechanistic schema of QPE has been proposed.

MODIFIED ATMOSPHERE AND TEMPERATURE GAMMA IRRADIATION EXPLORATORY STUDIES ON EVALUATING POLYOLEPHINES RECYCLING POTENTIAL

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The recyclabilizing of plastics treated with ionizing radiations is complicated due to the two competing processes: crosslinking and degradation. In a new approach, we intend to explore at a conceptual level the possibility of recycling polyolefins, within the range of doses/dose rates necessary to ensure microbial decontamination. Depending on the irradiation conditions (dose/dose rate, temperature/pressure, presence/absence of oxygen), a crosslinking type polymer can behave like one that under normal conditions degrades, and vice versa. Besides superior recycling (circular economy), as per the interest of industry partners, other specific use cases may be mentioned: obtaining materials for 3D printing technologies and/or screens for ionizing radiations.

The exploratory studies regarding the effect of gamma irradiations on polymeric materials proposed in present work aim to obtain new knowledge regarding the possibilities of predicting the prevalence of degradation vs. crosslinking processes, in different combinations of the physicochemical conditions during irradiation.

The effect of ionizing radiation treatment on polymeric wastes of interest for recycling and/or accelerated degradation in the polymer recycling experiments, a generation of NAPHTA (2%) was observed in PP irradiated at 45 kGy in the melt at 230°C. The degradative effect of temperature over time is much more important than that of irradiation. The synergistic effect (irradiation in the melt) is even stronger. HDPE shows minor changes but is generally stable under the special experimental conditions of temperature and absence of atmosphere. Thermal analysis and vibrational spectroscopy were performed to determine the structural modifications. A DSC method sensitive enough to detect the effects of accelerated degradation due to the synergistic effects of gamma ionizing radiation and temperature has been developed.

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SELECTIVE OXIDATION OF AMMONIA NITROGEN TO DINITROGEN BY A TETRAVALENT IRON OXIDE COMBINED WITH A SULFITE REDUCTION PROCESS UNDER UV IRRADIATION

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Among all kinds of nitrogen-containing wastewater, efficient denitrification of tailwater with low ammonia nitrogen ($\text{NH}_4^+\text{-N}$) concentrations has been a focus and has enormous challenges. Ferrites are considered to be highly effective green oxidizers for removing pollutants from wastewater due to their strong oxidizing properties. In the oxidation pollutants by ferrites process, intermediate iron species, such as tetravalent iron (Fe(IV)) usually have elevated reactivity. Herein, Fe(IV) was prepared by an alkaline-activated ferrate method and used to oxidize low concentrations of ammonia nitrogen under UV irradiation. In the developed $\text{Fe(IV)}/\text{UV}/\text{NH}_4^+$ system, 100% of $\text{NH}_4^+\text{-N}$ removal could be achieved at the initial pH 13, initial $\text{NH}_4^+\text{-N}$ concentration of 10 mg N/L, and Fe(IV) concentration of 1.83 mmol/L, and the oxidation product was mainly NO_2^- . Then, the NO_2^- product was further reduced to harmless dinitrogen (N_2) by sodium sulfite (Na_2SO_3) under UV irradiation and the effluent was neutral. The mechanism of conversion of $\text{NH}_4^+\text{-N}$ to N_2 by the $\text{Fe(IV)}/\text{UV}$ coupled with $\text{Na}_2\text{SO}_3/\text{UV}$ process was proposed. This work provides a new approach to the removal of ammonia nitrogen from wastewater by involving UV irradiation.

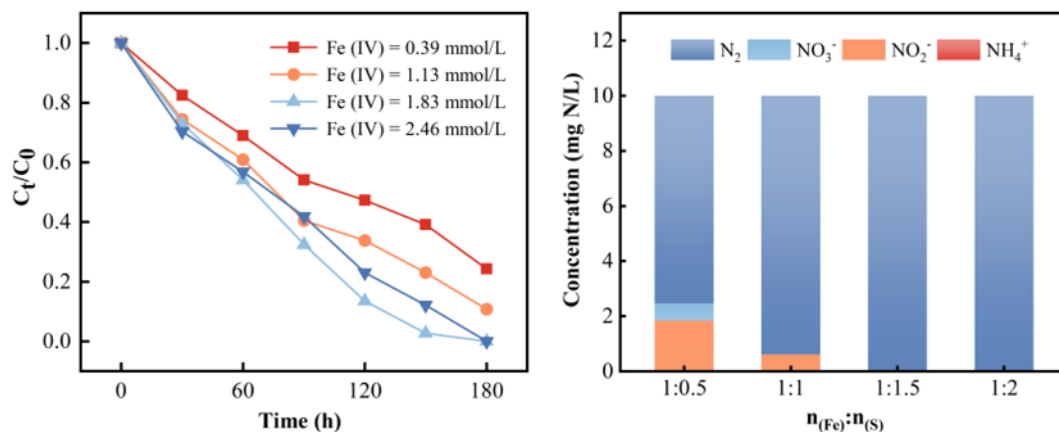


Figure 1. (a) $\text{NH}_4^+\text{-N}$ removal efficiency and (b) product of $\text{NH}_4^+\text{-N}$ oxidation by the $\text{Fe(IV)}/\text{UV}$ coupled with $\text{Na}_2\text{SO}_3/\text{UV}$ process.

H₂ EVOLUTION FROM HYDRATED WATER IN CEMENT COMPONENT CRYSTALS VIA γ -RAY RADIOLYSIS: EFFECT OF IRRADIATION TEMPERATURE

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Chemically bound water in ordinary Portland cement is reported to contribute little to radiolytic H₂ evolution [1]. H₂ evolution is very important factor for the safe long-term storage of radioactive species by solidification with concrete in future. In this study, the radiolysis of hydrate water in various cement component crystals was investigated as a function of irradiation temperature as mimic of decay heat.

Cement component crystals of calcium silicate hydrate (C-S-H) 0.83 (Ca/Si = 0.83), C-S-H 1.4 (Ca/Si = 1.40), ettringite (3CaO•Al₂O₃•3CaSO₄•32H₂O), and monosulfate (3CaO•Al₂O₃•CaSO₄•12H₂O) were supplied by Taiheiyo Consultant Co. Ltd. A powdery sample in an Ar-filled tube was irradiated with a dose of 1 kGy for water at the ⁶⁰Co γ -ray irradiation facility at Nagoya Univ. The sample temperature was controlled from 26 °C to 90 °C with tempered air heated with a heat gun. The amount of H₂ gas evolved from each sample by γ -ray irradiation was measured using a micro gas chromatograph.

C-S-H compounds as main components of ordinary Portland cement showed the considerably high G_{H_2} calculated based solely on the hydrated water portion ($G_{H_2}(\text{hyd})$) significantly greater than that of liquid water ($G_{H_2} = 0.45$) and were inclined to increase as the irradiation temperature increased (Figure 1). This result clearly shows that chemically bound waters can be sources of H₂ evolution by radiolysis, and $G_{H_2}(\text{hyd})$ can be affected by decay heat. Very low $G_{H_2}(\text{hyd})$ in ordinary Portland cement reported [1] is probably due to very slow diffusion of H₂ in inside of the cement.

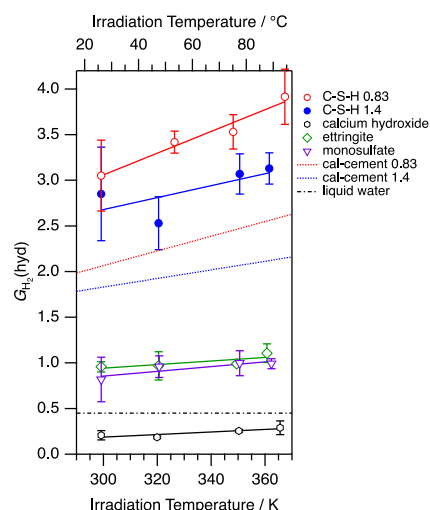


Figure 1. Irradiation temperature dependent $G_{H_2}(\text{hyd})$ for a series of component crystals of hardened cement.

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DEVELOPMENT OF BIOPOLYMER ACTIVE PACKAGING MATERIALS BASED ON CELLULOSE AND POLYETHYLENE GLYCOL

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Plastic packaging accounts for more than 30% of global plastic production, and the food packaging industry has the largest share of plastic packaging revenue worldwide. Traditional fossil fuel-based plastic packaging materials take more than 1,000 years to degrade. According to the UN Environment Program (UNEP) Plastic Waste Report, only 9% of all plastic waste was recycled between 2015 and 2018. Therefore, alternative food packaging materials are needed to overcome these effects and reduce the unsustainable use of plastic. The sustainability of biopolymers is related to the valorisation of waste and the biodegradability of the material. Conventional fossil fuel-based plastics often have ideal properties for protecting food from environmental conditions that increase food degradation. Therefore, bioplastics require equal or better mechanical and barrier properties to outperform traditional plastics.

Cellulose is perhaps the best raw material for removing plastic. It is the richest natural resource on Earth with more than 180 billion tons produced each year. As many industries move towards a greener future, cellulose-based plastics are becoming popular. It not only meets the economic and functional needs but is also sustainable for the long-term goals of the business.

Unfortunately, a small number of biopolymers are suitable for thermal and mechanical processing by extrusion, injection or thermoforming. The poor processability of biopolymers is the main obstacle to the development of packaging. One way to overcome this is to modify the structure to increase thermoplasticity. The addition of plasticizers such as polyethylene glycol can increase the plasticity and flexibility of the material, improving elongation at break values. Surface modifications of cellulose can improve properties that hinder the development of cellulose-based materials, such as sensitivity to water and moisture.

Among these modifications, radiation crosslinking of cellulose is one of the promising methods used to improve the properties of cellulose. The paper describes a new approach to the modification of native cellulose fibbers by poly (ethylene glycol) (PEG) impregnation and simultaneous radiation cross-linking using citric acid (CA). Also, treatment with ionizing radiation will ensure the necessary microbiological purity of the packaging material.

THE BEHAVIOUR OF METAL PARTICLES ENRICHED POLYMER FILMS IN RADIATION HARSH ENVIRONMENT

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It is known that electronic circuits and electronic devices are experiencing deterioration of their electrical properties in radiation-harsh cosmic environments. Specific radiation shields are used to protect this equipment against ionizing radiation. The development of non-toxic, radiation-resistant, lightweight coatings and thin film materials for radiation shielding which provides radiation attenuation corresponding to this of heavy lead, is one of the important research topics today.

In this study, radiation-induced variations of properties of polymer composites (thin films) enriched with Tungsten (VI) oxide, Tantalum (V) oxide, Tin, and Bismuth have been investigated.

Polymer composites were prepared following the procedure described in our previous paper [1] as follows: a certain amount of metal/metal oxide powder was mixed under continuous stirring with initially prepared 10% PVA water solution to obtain 20%, 40%, 60% wt enrichment of polymer composite with additives. It was found that due to saturation at higher concentrations, only a 20% wt concentration of added Ta₂O₅ in PVA solution was possible. Prepared solutions were cast into Petri dishes and left in the dark at room temperature for 72 hours to completely dry and form thin films. It should be noted that in the preparation phase, a small amount of water was exchanged with glycerol to get more flexible films.

To assess the impact of different beams on the properties of prepared films they irradiated with X-ray photons to doses up to 100 Gy in the medical X-ray therapy unit Gulmay D3225 (120 keV), medical linear accelerator Clinac DMX (Varian Medical Systems, 6 MeV), Leksell Gamma Knife[®] Icon (TM) facility with 192 ⁶⁰Co sources (av. 1.25 MeV), and also in the mixed photon/neutron beam at the cyclotron facility ACSI TR-19 (14-19 MeV).

Variations of physical properties of irradiated samples were analyzed using UV-Vis, AFM, and FTIR methods, based on which radiation impact of different beams on attenuation properties of experimental films were investigated and the feasibility of these films to provide required radiation shielding was discussed.

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FULLY RECYCLABLE 3D PRINTING COMPOSITES FOR CUSTOMIZED HEAD IMMOBILIZATION MASKS IN RADIOTHERAPY

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Immobilization masks are an essential tools for ensuring the precise targeting of radiotherapy treatments by restricting the movements of a particular anatomical segment. Their applications extend to scenarios where the superposition of various medical images is vital for accurately identifying and characterizing certain pathologies. However, current head immobilization systems can induce claustrophobia and discomfort in patients due to their structural characteristics, both during the fitting process and while in use. 3D printing technologies can help resolve these issues by developing highly precise 3D-printed mask systems based on patient geometrical information extracted from CT images. This work aims to assess the stiffness and strength of in-house produced 3D printing composite material for use in the radiotherapy field with a special focus on the effect of irradiation and recycling on their mechanical properties. Additionally, a comprehensive comparison of the new materials to established thermoplastic mask systems from two commercial companies (Macromedics and Orfit) was performed.

Experimental evaluation of the mechanical properties of in-house produced ABS filament composites containing 0% - 20% of Bi₂O₃ fillers was performed using ElectroPuls® E10000 linear-torsion machine (Instron) following ISO527-2 standard requirements. Evaluated samples included virgin and recycled materials (up to 10 times) irradiated with 6 MeV photons in the medical linear accelerator Clinac DMX (Varian Medical Systems) to doses up to 100 Gy. The mechanical properties of thermoplastic materials used in two commercial mask systems were investigated using the same methodology. In addition, the static behavior of the 3D-printed masks under typical loading conditions was assessed using ANSYS simulation software. A linear elastic material model was used with results valid up to the stresses lower than the yield point of the material.

The newly developed 3D printing composites containing 20% Bi₂O₃ filler were 3 times stronger (UTS = 7.0 MPa vs 20.9 MPa) and 6.6 times stiffer (E= 0.3 GPa vs 2.0 GPa) than commercial thermoplastics commonly used for fabrication of fixation devices. The mechanical properties of ABS/Bi₂O₃ composites were not affected by 10 recycling cycles as opposed to pure ABS which had a decrease in tensile strength (from 25.1 to 21.0 MPa) and Young's modulus (from 2.5 to 1.3 GPa). Moreover, ABS/Bi₂O₃ composites were resistant to the damaging effect of ionizing radiation, indicating their potential for applications in radiotherapy.

Performed simulation showed that the maximum equivalent von Mises stress resulting from typical head movement (15.3 MPa in case of lateral force) was significantly lower than the yield points of the studied recycled and irradiated 3D printing materials (19.7-25.1 MPa), thus providing a satisfactory safety factor. In addition, the maximum mask displacements were in the range of 3.31-7.86 mm and consistent with a desired immobilization.



2 MeV ION IRRADIATION OF PORPHYRIN IN ITS THREE FORMS

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Water-soluble synthetic porphyrins are extensively studied as potential photosensitizers in photodynamic therapy (PDT) and radiotherapy of cancer (Bonnett, 1995; Lapeš et al., 1996; Gelfuso et al., 2011; Lang et al., 2004; Luksiene et al., 2006, 1999; Kassab, 2009) as well as in dye-sensitized solar cells (Shin et al., 2010). Porphyrins demonstrate also the photodynamic activity against numerous diseases.

The parent of porphyrins is porphine, a rare chemical compound of exclusively theoretical interest. Substituted porphines are called porphyrins. With a total of 26 π -electrons, of which 18 or 16 π -electrons form a planar, continuous cycle, the porphyrin ring structure is often described as aromatic. In case of the free porphyrins, the less planar 18 electron delocalization, while in case of metallo porphyrins the more planar 16 conjugation cycle occurs. These electron structures have effect on their degradation efficiency as well.

In this work, 2 MeV ion radiation induced radiolysis of water-soluble tetrakis(4-sulfonatophenyl)-porphyrin, its protonated and its Zn metalized version were studied. The 2 MeV proton irradiations were achieved on a special in-air ion beam irradiation setup (at the Atomki Tandetron accelerator, Debrecen, Hungary). The decoloration was followed by a UV/VIS spectrophotometry.

As a result, very different decoloration rates were found, at very high dose (70-140 kGy).

DOSIMETRY APPLIED TO LOW ENERGY ELECTRON BEAM

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For Low Energy Electron Beam (LEEB) irradiation, the widely accepted dosimetric method for approximating the ‘surface’ dose, endorsed by both industry and academia, revolves around the dose absorbed in the first micrometer: D_{μ} [1]. Based on measurements in 18 μm thick dosimeters and extrapolation using Monte Carlo simulation, this technique could not be validated at this stage and could therefore lead to either under or overestimation of the surface dose of a product. Overestimation of the dose might facilitate the propagation of bacteria or viruses on the surface of the treated product if the minimal dose required to eradicate the bacteria is not achieved. Conversely, an underestimation could lead to an overdosage potentially causing undesired modifications to the surface of the product. Consequently, we became interested in developing new dosimetric systems dedicated to low energy electrons beam dosimetry.

We investigated the evolution, under 10 MeV electron beam irradiation, of luminescence intensities of several fluorescent compounds in various liquid medium (Figure 1). These compounds exhibited different quenching behaviors, enabling a ratiometric determination of the dose through fluorescence measurements. Polymers containing two fluorescent compounds have been prepared according to a published procedure [2] in microplate and confocal microscopy dishes. Their absorbance and luminescence properties were examined before and after irradiation using spectrophotometry and in-depth confocal microscopy. Figure 2 (left image) unveils a dose dependent image within the first hundreds of micrometers of the polymer with its depth dose profile on the right of Figure 2. Ongoing investigations and analyses are currently underway.

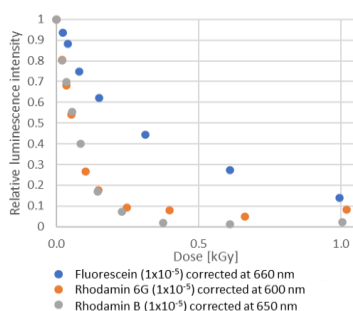


Figure 1. Evolution of the normalized luminescence intensity of several luminescent compounds exposed to increasing doses to a 10 MeV electron beam.

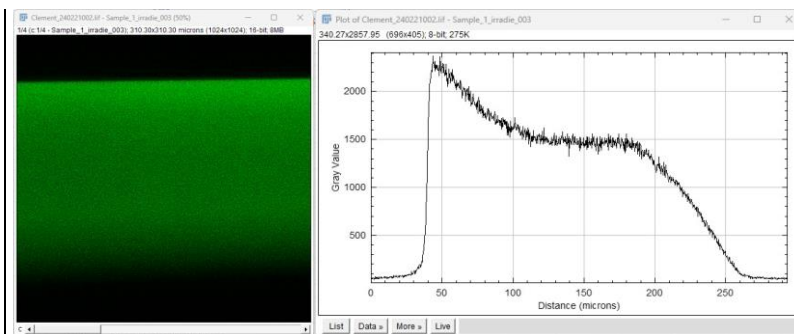


Figure 2. Confocal microscopy image and profile of a sample irradiated with 200 keV

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	August 23	August 24	August 25	August 26	August 27	August 28	
7:00		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	
9:00					Invited lecture Jurkin		
9:30					Invited lecture Gohdo		
10:00		Invited lecture Kusumoto	Invited lecture Ferreira	Invited lecture Le Caër	Prouzová Procházková		
10:20		Sabol	Invited lecture Mészáros	Invited lecture Casimiro	Lakatos		
10:30					Rurarz		
10:40		Sabol					
10:50							
11:00		Juha	Kiss	Mustafayev	Sütekin		
11:10							
11:20			Tataru	Weng			
11:30							
11:40			Lugao	Juhász	Lunch		
11:50							
12:00		Lunch	Lunch	Havlinová			
12:20					Lunch		
14:00	Registration	Invited lecture Driscoll	Invited lecture Al-Sheikhly	Invited lecture Lacroix	Conference excursion		Travel home
14:30		Invited lecture Al-Sheikhly	Invited lecture Chu	Invited lecture Pasanphan			
15:00		Invited lecture Feldman	Sun	Marinov			
15:20			E. Ergun	Driscoll			
15:30		Coffee break					
15:40			Coffee break	Coffee break			
16:00		Invited lecture LaVerne	Invited lecture J. Wang	Invited lecture Robertson			
16:30		Invited lecture Ulanski	He	Madureira			
16:50			S. Wang	Krleski			
17:00		Invited lecture Coqueret		Poster session			
17:10							
17:30							
18:00							
18:30							
19:00	Dinner	Dinner	Dinner	Dinner			
19:30					Conference Dinner		
22:30							